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FIELD RESULTS IN A MILLET BREEDING EXPERIMENT[1]

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IN an earlier paper, the authors (5)[3] discussed certain problems encountered in the breeding of millet. The present paper reports results of actual field trials, together with a description of field technic employed in an extensive millet breeding project.

SIZE AND SHAPE OF PLAT

A selected strain of millet (No. 48) was planted on a very level field where uniform crops had been grown previously. The rows were 100 feet long (1 foot = 1/3 meter) and 1 foot apart. There were 100 rows with additional border rows for protection. The seeding was heavy enough to insure a good stand. When the seedlings reached a height of about 2 inches, thinning was done, leaving the plants 3 inches apart. Thus, an almost perfect stand was obtained. In harvesting, after removing the border rows and the superfluous ends in the test rows, 15-foot lengths were harvested as a unit. Thus, 600 rows were obtained. The bundles were then hung in the seedhouse until air dried. After threshing, the seeds from each bundle were put in separate paper sacks and weighed. The results are shown in Table 1.

The analysis of variance method devised by Fisher (1) was used in analysing the data. No attempt is made to describe the detailed calculations. In general, the field was divided each time into blocks that would accomodate 10 hypothetical varieties. The variation within the block was taken to be the experimental error from which the standard deviations were calculated. In Table 2, is given the analysis of variance for plats of one row each 15 feet long

The standard error of the single plat was 47.78 grams, or 18.73% of the mean yield of all the plats concerned (255.14 grams).

The 600 plats in the field could be combined in various ways to form plats of varying size and shape. On the basis of 10 varieties per block, it is possible to consider hypothetical plats 1, 2, 5, and 10 rows

[1]Contribution from the College of Agriculture, Honan University, Kaifeng, Honan, China. Received for publication July 2, 1935.
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[3]Figures in parenthesis refer to "Literature Cited", p. 15.

TABLE 1.—*Yield of millet in grams from 600 single-row plats each 15 feet long.*

Plat No.	Yield	Plat No.	Yield	Plat No.	Yield	Plat No.	Yield	Plat No.	Yield	Plat No.	Yield
1	295	101	333	201	243	301	231	401	176	501	403
2	273	102	280	202	235	302	202	402	251	502	305
3	200	103	198	203	241	303	207	403	178	503	361
4	311	104	146	204	292	304	300	404	175	504	386
5	184	105	343	205	257	305	275	405	246	505	391
6	336	106	306	206	292	306	265	406	214	506	416
7	277	107	228	207	246	307	216	407	282	507	321
8	319	108	265	208	201	308	281	408	217	508	317
9	237	109	272	209	289	309	264	409	266	509	390
10	328	110	255	210	303	310	289	410	225	510	252
11	279	111	232	211	255	311	262	411	254	511	344
12	282	112	256	212	226	312	366	412	266	512	287
13	291	113	289	213	262	313	328	413	281	513	326
14	365	114	177	214	301	314	223	414	237	514	329
15	215	115	209	215	251	315	220	415	263	515	245
16	273	116	207	216	189	316	251	416	275	516	318
17	248	117	227	217	180	317	280	417	232	517	245
18	233	118	226	218	236	318	235	418	242	518	266
19	212	119	212	219	238	319	221	419	239	519	240
20	240	120	208	220	308	320	196	420	219	520	263
21	322	121	271	221	282	321	248	421	258	521	230
22	177	122	176	222	182	322	195	422	164	522	320
23	262	123	237	223	330	323	171	423	200	523	217
24	195	124	181	224	178	324	187	424	218	524	375
25	202	125	278	225	263	325	216	425	225	525	243
26	222	126	192	226	214	326	205	426	328	526	324
27	208	127	256	227	232	327	203	427	230	527	223
28	234	128	159	228	183	328	267	428	245	528	328
29	307	129	268	229	266	329	233	429	207	529	244
30	286	130	211	230	147	330	184	430	259	530	339
31	233	131	242	231	342	331	187	431	215	531	257
32	301	132	221	232	254	332	263	432	354	532	295
33	291	133	260	233	379	333	229	433	206	533	230
34	267	134	212	234	178	334	223	434	279	534	322
35	214	135	233	235	375	335	245	435	206	535	196
36	409	136	253	236	200	336	257	436	320	536	275
37	305	137	264	237	360	337	198	437	174	537	261
38	333	138	237	238	271	338	232	438	365	538	359
39	245	139	247	239	376	339	282	439	210	539	213
40	279	140	156	240	189	340	246	440	474	540	445
41	254	141	246	241	252	341	264	441	203	541	254
42	296	142	201	242	254	342	171	442	380	542	449
43	220	143	246	243	247	343	200	443	261	543	261
44	211	144	230	244	186	344	204	444	294	544	412
45	298	145	183	245	260	345	215	445	215	545	220
46	227	146	213	246	202	346	247	446	353	546	387
47	229	147	267	247	206	347	221	447	264	547	231
48	277	148	255	248	219	348	264	448	306	548	355
49	221	149	243	249	234	349	185	449	224	549	218
50	302	150	290	250	284	350	207	450	290	550	248
51	234	151	186	251	210	351	158	451	253	551	212
52	248	152	241	252	311	352	280	452	268	552	351
53	275	153	270	253	236	353	220	453	261	553	275
54	257	154	261	254	275	354	216	454	318	554	334
55	275	155	262	255	166	355	209	455	268	555	282
56	266	156	226	256	232	356	205	456	315	556	385
57	263	157	297	257	258	357	281	457	249	557	298
58	285	158	164	258	228	358	225	458	318	558	350

TABLE 1.—*Continued.*

Plat No.	Yield	Plat No.	Yield	Plat No.	Yield	Plat No.	Yield	Plat No.	Yield	Plat No.	Yield
59	298	159	272	259	249	359	203	459	204	559	174
60	193	160	184	260	158	360	230	460	215	560	318
61	240	161	313	261	321	361	252	461	211	561	296
62	240	162	178	262	188	362	209	462	294	562	342
63	237	163	293	263	302	363	213	463	224	563	175
64	251	164	228	264	170	364	266	464	244	564	176
65	319	165	182	265	156	365	203	465	230	565	209
66	228	166	237	266	174	366	218	466	299	566	254
67	276	167	252	267	302	367	235	467	253	567	210
68	250	168	254	268	228	368	222	468	252	568	316
69	166	169	304	269	231	369	242	469	180	569	224
70	276	170	274	270	246	370	261	470	283	570	289
71	205	171	199	271	279	371	208	471	179	571	224
72	287	172	207	272	287	372	241	472	323	572	245
73	252	173	225	273	288	373	250	473	264	573	212
74	279	174	229	274	245	374	276	474	264	574	292
75	277	175	257	275	290	375	225	475	199	575	225
76	351	176	207	276	281	376	226	476	319	576	244
77	274	177	236	277	301	377	201	477	246	577	319
78	345	178	244	278	253	378	215	478	271	578	327
79	274	179	205	279	301	379	238	479	262	579	268
80	332	180	230	280	213	380	238	480	317	580	231
81	290	181	193	281	251	381	183	481	190	581	297
82	396	182	256	282	277	382	256	482	344	582	221
83	234	183	263	283	246	383	256	483	255	583	268
84	306	184	182	284	284	384	216	484	277	584	277
85	259	185	200	285	282	385	212	485	224	585	220
86	287	186	282	286	275	386	287	486	337	586	234
87	235	187	225	287	235	387	228	487	191	587	210
88	281	188	216	288	240	388	239	488	250	588	376
89	212	189	248	289	297	389	203	489	244	589	239
90	232	190	290	290	227	390	237	490	483	590	304
91	204	191	248	291	236	391	226	491	249	591	258
92	242	192	220	292	208	392	208	492	302	592	359
93	232	193	243	293	215	393	258	493	339	593	266
94	314	194	273	294	173	394	348	494	347	594	275
95	212	195	263	295	251	395	198	495	341	595	279
96	254	196	244	296	231	396	236	496	401	596	280
97	220	197	241	297	189	397	219	497	245	597	358
98	224	198	218	298	194	398	214	498	320	598	283
99	270	199	208	299	205	399	290	499	269	599	278
100	175	200	145	300	196	400	234	500	360	600	308

TABLE 2.—*Analysis of variance of single-row plats 15 feet long.*

Variation	Degrees of freedom	Sums of squares	Mean square	S. D.
Between blocks...	59	474682.64	—	—
Within blocks...	540	1232553.60	2282.506	47.78
Total between plats............	599	1707236.24	—	—

wide and 15, 30, 45, and 90 feet long. Using these combinations, the entire field is considered each time in studying the variance between plats. In Table 3 is given the standard error in percentage of the mean for these combinations.

TABLE 3.—*Standard error in percentage of the mean of yields of plats for varying size and shape.*

Width in rows	Length of row in feet			
	15	30	45	90
1	18.73	14.58	12.60	8.38
2	12.40	9.13	8.23	6.26
5	9.82	7.28	6.78	5.09
10	8.66	5.92	5.62	—

As a whole, the standard error in percentage of the mean decreases with an increase in the size of plat. Increasing the length of rows from 15 feet to 30 feet results in a marked reduction in the standard error, but by keeping the same length of row (15 feet) and increasing the width to two rows, a still greater reduction in the standard error is obtained. It is probable that the two-row width may be the most favorable width on this field due to soil heterogeneity.

Further increase in the length from 30 feet to 45 feet results in a slightly reduced standard error, and still further reduction is obtained when the length is increased to 90 feet. Increasing the width of plats from two rows to five rows results in some reduction in the standard error. A further increase to 10 rows also results in a reduced standard error, but not altogether in proportion to the area of land used

In Table 4 is given the number of replications needed to reduce the standard error of the mean to 2%. The standard error of the mean of several replications is found by dividing the standard error of a single plat by the square root of n, when n is the number of replications

Table 4.—*Theoretical number of replications needed to reduce the standard error of the mean to 2%.*

Width in rows	Length of row in feet			
	15	30	45	90
1	87.8	53.1	39.7	17.6
2	38.4	20.8	17.0	9.8
5	24.1	13.2	11.5	6.5
10	18.7	8.8	7.9	—

With a standard error of the mean of 2%, the standard error of a difference would be $2\sqrt{2}$, or 2.83%. If twice the standard error of difference is adopted as a level of significance, a difference exceeding 5.66% could then be considered significant with the replications given in Table 4. It can be seen that as the size of the plat is increased to a certain maximum further increase of the size will be disproportionate to the efficiency of the land used.

The efficiency of the use of land was calculated according to the method used by Immer (3) and the results are shown in Table 5.

In general, the smaller the plat, the more efficient is the use of land as Immer (3) and Immer and Raleigh (4) found to be true with sugar beets and Reynolds, *et al.* (7) with cotton.

TABLE 5.—*Percentage efficiency in use of land of plats varying in size and shape.*

Width in rows	Length of row in feet			
	15	30	45	90
1	100.0	82.5	73.6	83.2
2	113.9	105.1	86.3	74.5
5	72.7	66.2	50.8	45.1
10	46.7	50.2	37.0	—

In the present experiment with millet it was found that the most efficient use of the land resulted from plats 15 feet long and two rows in width. From this, it can be said that one-row plats 15 feet long would be a disadvantage in any experiment for the variation is too great, judging from the size of the standard error. Two-row plats 15 feet long and replicated frequently enough to reduce the error to the level desired would be most satisfactory in laying out experiments on this field. Maintaining the same width of plat, but increasing the length to 30 feet when the experimental area is not a limiting factor also seems to be very satisfactory. Of course, with the increase in the size of plat, the replication is correspondingly reduced to maintain the same level of error.

VARIETAL COMPETITION

In variety trials of any crop, competition between varieties may be a serious factor. With the existence of competition among the varieties, border rows for proper protection are grown and are discarded in harvesting. Consequently, more land and labor are required to grow the crop. If such competition does not exist, it means an economy of land and labor. Love and Craig (6), in describing the methods used in cereal investigations at the Cornell University Experiment Station, describe the single-row test and add that, "In order to prevent any effect which may be caused by two unlike sorts growing together, the different strains are arranged according to earliness and other characters so as to reduce this source of error to a minimum."

In 1933, two separate plantings of the same 10 farmers' varieties of millet were grown to answer this question, and for other purposes as well. The varieties were arranged systematically. There were three rows in the plat for each variety and the rows were 15 feet in length and 1 foot apart. Each variety was replicated 10 times, making 10 plats for each variety. The first planting was sown on April 26 and the second on June 8. The method used by Hayes and Arny (2) was applied to determine the existence of varietal competition. The results obtained were negative, r being -0.0581 ± 0.0712 for the first planting and -0.0539 ± 0.0713 for the second. It was noted, however, that on account of the dry weather in 1933 and the consequent very poor growth, varietal competition might not have manifested itself fully. By calculating the yield on a percentage basis and by taking the yield of the central row of each variety, which is protected from competition by its border rows, as 100, any competition would show itself by the increase or decrease of percentage yield

for the border rows under competition as compared with their central row. A corresponding decrease or increase of the percentage yield for the border rows as compared with their central row of the variety at each side of the said variety would signify the existence of competition. Some indication of such competition was noted. The same two plantings were repeated in 1934 on the same experimental ground as the previous year, and they were also planted approximately on

TABLE 6.—*Yield data (in grams) for the 10 varieties of millet grown in two separate plantings in 1933 and 1934, with percentage yields based on the center rows as 100.*

Variety	1933				1934				Total	
	First planting		Second planting		First planting		Second planting			
	Yield	%	Yield	%	Yield	%	Yield	%	Yield	%
A*	167.1		163.0		207.2		292.7		830.0	
	122.5	73	159.9	98	199.4	96	302.2	103	784.0	94
B	168.4	107	210.7	117	265.9	114	304.8	93	949.8	105
	157.9		180.3		232.8		329.4		900.4	
	171.5	109	180.3	100	230.9	99	317.0	96	899.7	100
C	175.3	109	201.3	99	248.3	95	349.7	99	974.6	100
	160.9		203.3		260.5		352.5		977.2	
	157.9	98	184.4	91	254.0	98	303.0	86	899.3	92
D	158.5	114	181.1	99	271.1	98	357.9	108	968.6	104
	139.3		183.2		276.8		331.5		929.9	
	166.1	119	214.8	118	292.7	106	334.4	101	1008.0	108
E	143.6	92	183.8	91	132.5	95	297.1	88	757.0	91
	155.3		202.6		140.2		337.1		835.2	
	130.0	84	188.8	93	163.7	117	305.0	90	787.5	94
F	180.8	97	232.7	122	198.0	93	316.2	100	927.7	102
	186.9		190.5		213.2		314.7		905.3	
	171.7	92	224.9	118	222.1	104	317.8	101	936.5	103
G	155.6	96	210.3	101	168.1	81	325.7	109	859.7	98
	162.4		207.3		206.5		300.1		876.3	
	168.8	104	224.7	108	198.5	96	302.9	101	894.9	102
H	183.4	86	223.3	93	246.4	93	351.4	108	1004.5	97
	205.4		240.3		265.1		325.4		1036.2	
	200.3	98	206.7	96	245.2	92	344.4	106	996.6	96
I	152.4	86	205.7	94	207.8	96	306.1	100	872.0	95
	178.0		219.3		216.3		307.3		920.9	
	192.9	108	203.1	93	207.5	96	323.1	105	926.6	101
J	172.5	101	207.3	101	200.8	88	315.9	103	896.5	98
	171.5		205.4		227.0		307.3		911.2	
	147.9	86	250.2	122	215.5	95	302.5	98	916.1	101
A*	143.2	82	169.8	102	274.8	132	296.1	96	856.9	100
	174.5		165.8		207.9		307.9		856.1	

*The same variety.

the same date in the different plantings as in 1933. A summary of the yield data of these four plantings for the two years is shown in Table 6.

From Table 6 it can be seen that there might be competition between varieties A and B, D and E, E and F, F and G, and G and H. Of these, the competition between D and E is consistent throughout all four plantings. Variety D is a late variety, whereas E is a comparatively early variety. In yielding ability, however, it varies with the season. Earliness here may contribute greatly to competition. Apart from these two varieties, it is rather doubtful whether competition actually exists between the other varieties. Since the varieties used are farmers' varieties, they show variation in height of plant, earliness, type of head, etc. Perhaps this may explain some of the contradictory results obtained in these four plantings.

In order to pursue this question of varietal competition still further, another experiment was carried out in which 30 selected strains were used with varying earliness, height of plant, stooling ability, and yield of grain. Systematic arrangement was followed. Each strain was planted in five-row plats and was replicated five times. Each row was 17 feet long and 1 foot apart, and at harvest 1 foot from each end of the row was discarded, so that only 15 foot lengths were harvested for each row. Sowing for this experiment was done on June 6. The seedlings were thinned twice so that finally the distance between plants was 3 inches. The stand was thus made perfect. The precipitation during the growing season was very abundant so that the growth was at its maximum. If varietal competition existed, it should have manifested itself to its full extent. Stadler's method (9) for calculating the relation of competition to various characteristics of the competing varieties was followed closely, and the results are shown in Table 7.

TABLE 7.—*Correlation coefficient of competition with various characteristics.*

Character	Correlation coefficient
Yield	—.458
Height	+.165
Heading	+.577

When $n = 27$, r at 5% level of significance is .367 and at 1% it is .470 in Fisher's tables (1). These results differ greatly from those which were obtained with barley, oats, and wheat by Stadler (9), who found significant positive correlation between competition with yield and variable negative correlation with date of heading. With millet, the results were just in the reverse order and were significant in both cases. A positive correlation was obtained with height but it was insignificant. From these results it can be seen that the low-yielding and the late varieties are the ones which have, in general, profited from competition.

With maximum conditions for growth, competition between varieties does exist. Thus, in varietal trials with millet, even with random arrangement, it is wise to consider this problem.

PLANTING DISTANCE BETWEEN PLANTS IN VARIETAL TRIALS

In varietal trials with millet, the distance between plants is a problem to be considered. The common practice for the farmers in the vicinity of Kaifeng in Honan Province, China, is to put the millet in drills with rows about 7½ inches apart. In thinning, a clump of seedlings with varying numbers, usually from two to five, is left, leaving about 5 inches between clumps. In our varietal trials with this crop, the rows are farther apart, i. e., 1 foot. In the past, two plants in hills 4 inches apart or one plant in hills 3 inches apart were left in thinning, but the justification of this practice is open to question, hence an experiment was carried out in order to arrive at a solution. The variety used in this experiment was the selected strain No. 48 which is a high yielder, stools well, and matures fairly late. Five planting distances were considered, *viz.*, 2, 4, 6, 8, and 10 inches apart. These were arranged in a five by five Latin Square. Five rows formed a plat for each treatment. The rows were 17 feet long and 1 foot apart. In harvesting, only the central three rows in the plat were used, and 1 foot at each end of the row was discarded so as to avoid any effect of competition or border effect. The land on which this experiment was carried out was very level and was relatively uniform. Several uniform crops were grown prior to this experiment. Planting and cultivating were about the same as those described above for the other experiments, except that the seedlings were thinned to the distance required for each treatment. One plant was left in each hill. Table 8 gives the average yields of three central rows 15 feet long for the different planting distances.

TABLE 8.—*Yield in grams for different planting distances.*

Planting distance*	Yield, grams	Planting distance*	Yield, grams	Planting distance*	Yield, grams	Planting distance*	Yield, grams	Planting distance*	Yield, grams
B	257	D	245	E	182	A	203	C	231
E	230	A	283	B	252	C	204	D	271
A	279	E	245	C	280	D	227	B	266
C	287	B	280	D	246	E	193	A	334
D	202	C	260	A	250	B	259	E	338

*A = 2 in., mean yield 269.8 grams; B = 4 in., mean yield 262.8 grams; C = 6 in., mean yield 252.4 grams; D = 8 in., mean yield 238.2 grams; and E = 10 in., mean yield 237.6 grams.

TABLE 9.—*The analysis of variance of data in Table 8.*

Variation due to	Degrees of freedom	Sums of squares	Mean square
Columns	4	13601.36	——
Rows	4	6146.16	——
Treatments	4	4156.56	1039.14
Error	12	12667.28	1055.61
Total	24	36571.36	

From Table 9, it can be seen that the mean square of treatment is smaller than that of error, and certainly it denotes the insignificance of the treatments. The standard error of the mean of 5 is $\sqrt{\frac{1055.61}{5}} = 14.53$. Any significant difference between two treatments would be $14.53 \times \sqrt{2} \times 2.18 = 44.79$ grams. Table 10 shows the actual difference between different planting distances.

TABLE 10.—*Difference in yield in grams between different planting distances with column used for standard of comparison.*

	B	C	D	E
A	7.0	17.4	31.6	32.2
B	—	10.4	24.6	25.2
C	—	—	14.2	14.8
D	—	—	—	0.6

It may be concluded therefore, that the yield of millet varies directly with the planting distance, but the difference is insignificant statistically even between treatments A and E which gave the highest and lowest yields, respectively. It can readily be seen that the number of plants in the row varies inversely as the planting distance, for we have the same length of row in each case. As the plants are farther apart in the row, stooling per plant might perhaps increase, thus making up in yield and offering an explanation for the lack of significance obtained with the different treatments. Table 11 shows the stooling per plant for the different treatments. In sampling, the first 10 plants of the row were counted and then subsequently averaged.

TABLE 11.—*Average number of stools per plant for different planting distances.*

Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	Average stooling
B	3.77	D	4.03	E	4.02	A	2.60	C	3.83	A	2.894
E	4.02	A	3.00	B	3.00	C	4.33	D	4.03	B	3.624
A	3.50	E	5.37	C	3.02	D	3.30	B	4.00	C	3.750
C	3.97	B	4.02	D	3.73	E	3.33	A	2.47	D	3.738
D	3.60	C	3.60	A	2.90	B	3.33	E	5.53	E	4.454

*See Table 8 for explanation of symbols.

As expected, the number of stools per plant varied directly as the distance between plants. However, treatment D does not follow this rule strictly, though is not very far off. The analysis of variance is given in Table 12.

When $n_1 = 4$, $n_2 = 12$, F at 5% level of significance is 3.26 and at 1% point is 5.41, according to Snedecor (8). Treatments in this experiment do have some significance. The significant difference

between two treatments is 0.797. Table 13 shows the comparative difference between the treatments.

In order to show the relation between the yield of each plat and the number of stools per plant for different planting distances, etc., analysis of variance and covariance is given in Table 14.

TABLE 12.—*Analysis of variance of data in Table 11.*

Variation due to	Degrees of freedom	Sums of squares	Mean square	F
Columns	4	2.04452	—	—
Rows	4	.34340	—	—
Treatments	4	6.13776	1.53444	4.58
Error	12	4.01712	.33476	—
Total	24	12.54280		

TABLE 13.—*Difference in number of stools per plant for different planting distances.*

	B	C	D	E
A	—.73	—.856	—.844	—1.560
B	—	—.126	—.114	— .830
C	—	—	.012	— .704
D	—	—	—	— .716

TABLE 14.—*Analysis of variance and covariance.*

Variation due to	Degrees of freedom	Sums of squares (x^2) A	Sums of products (xy) B	Sums of squares (y^2) C	B^2/A	
Columns	4	2.04452	139.0720	13601.36	—	—
Rows	4	.34340	1.5460	6146.16	—	—
Treatments	4	6.13776	—132.6160	4156.56	2865.38	3347.19
Error	12	4.01712	43.9940	12667.28	481.81	
Total	24	12.54280	51.9920	36571.36		
Treatment + error	16	10.15448	— 88.622	16823.84	773.407	

The regression coefficient $b' = \frac{43.994}{4.01712} = 10.951$. To test its significance, we have $B^2/A = 481.81$ Hence, the analysis of the yield error gives the following:

	Degrees of freedom	Sums of squares	Mean square
Due to regression	1	481.81	481.81
Due to deviations	11	12185.47	1107.77
Total error	12	12667.28	

This is not significant, of course, for the mean square due to regression is smaller than that due to deviations. Using the equation $Y = y - b'(x - \bar{x})$ to correct the mean yield y for regression, we get the results as shown in Table 15.

TABLE 15.—*Correction of the mean yield.*

Treatment	Stooling (x)	$x - \bar{x}$	$b' (x - \bar{x})$	Yield (y)	$Y = y - b' (x - \bar{x})$
A............	2.894	— .798	—8.7389	269.8	278.5
B............	3.624	— .068	— .7447	262.8	263.5
C............	3.750	.058	.6352	252.7	252.1
D............	3.738	.046	.5037	238.2	237.7
E............	4.454	.762	8.3447	237.6	229.3
	$\bar{x} = 3.692$			$\bar{y} = 252.22$	

The last column of Table 15 gives the yield for different treatments corrected for equal number of stools. Table 16 gives the analysis of variance corrected for number of stools.

TABLE 16.—*Analysis of variance corrected for number of stools ($C—B^2/A$ from Table 14).*

	Degrees of freedom	Sums of squares	Mean square
Treatment and error..	15	16050.433	——
Error....	11	12185.470	1107.77
Difference..	4	3864.963	966.24

This is again insignificant. We may conclude, therefore, that the number of stools might contribute some in making up the yield from what is lost in plant number per row when spacing between plants is farther apart. The yield, however, may depend on some other factors, such as the number of seeds per plant, the length of head, the height of plant, the weight of seeds, and what not. It is hoped that studies now in progress will throw some light on this problem.

In conducting varietal trials with millet, plants spaced 2 or 3 inches apart should give the best results. This will not only give the maximum yield, but it will also nullify the effect of missing hills, for there are more plants for the same length of row than when the spacings are farther apart.

RELATION OF YIELD COMPONENTS TO YIELD OF GRAIN

The yield of grain in millet is a very complex character. It is the end result and sum total of the activities of the plant. There are two main forces that determine the amount of seed produced, *viz.*, internal and external. The plant breeder is interested chiefly in the heritable traits of the strain or variety, the internal force. These traits should be manifested more clearly if the strains or varieties are grown under identical conditions.

In selection work with millet, however, one who merely goes to the field would have no idea whatsoever how to select the high-yielding plants. Also, in hybridization, the plant breeder will be at a loss to select the right parents so as to create a high-yielding strain artificially. For this reason, the following experiment was carried out to determine the components for yielding ability in millet.

Fifty selected strains were used in this study. The rows were 5 feet long and 1 foot apart, with hills 4 inches apart. There were altogether 10 replications for each strain, making 10 blocks. Each block accomodated 50 strains in a random fashion. In harvesting, all the plants in

TABLE 17.—*Average values of yield components for 50 strains of millet.*

Strain No.	Av. yield per plant, grams	Stools per plant	Height of plant, in.	Length of head, in.	Weight of 10,000 kernels, grams	Days to heading
469	16.5	3.2	45.2	17.5	28.8	16.9
11	15.2	3.3	38.3	13.7	26.4	11.6
162	18.2	3.5	41.0	16.5	26.6	14.9
1082	12.5	3.5	39.7	14.6	28.0	15.7
1211	15.2	3.4	42.7	15.8	26.0	16.7
667	12.1	5.8	33.5	9.8	22.9	13.2
655	13.3	4.3	32.9	12.4	22.9	11.2
48	14.9	5.6	40.1	13.6	23.4	18.4
724	12.9	4.5	34.8	13.7	24.3	12.1
472	16.8	4.3	41.2	16.1	27.8	15.9
635	13.1	3.7	43.4	13.5	26.5	20.6
771	13.3	3.9	44.0	17.1	25.5	19.7
——*	5.7	10.2	34.1	5.9	19.8	1.1
142	13.4	2.5	38.9	17.5	26.2	12.2
1514	14.0	2.7	43.4	14.8	26.5	14 6
704	10.0	2.4	34.9	10.0	25.1	10.5
51	13.5	3.1	40.0	13.3	25.7	12.7
461	15.3	3.8	41.2	15.8	27.9	15.7
1620	10.9	3.3	40.3	15.0	23.5	19.9
721	10.9	2.7	34.9	12.5	25.3	11.3
1588	11.4	1.7	37.0	16.1	23.6	10.6
89	13.7	3.9	40.3	18.2	23.7	14.9
71	14.7	2.7	42.4	18.5	23.8	15.1
1149	12.9	4.1	38.3	15 2	23.3	16.5
1419	14.5	4.4	43.1	12.0	25.4	18.7
1286	14.9	4.1	38.5	14.1	27.6	14.0
1567	15.8	4.7	38.4	9.9	25.4	15.3
447	10.9	2.7	33.5	11.5	23.7	10.3
781	15.8	6.2	42.9	13.2	24.9	19.6
558	13.9	4.8	34.4	12.7	25.9	12.9
475	17.5	4.3	42.1	18.8	25.9	15.1
1138	15.5	6.4	40.1	14.2	22.7	17.5
138	12.4	3.4	37.9	14.4	27.3	12.5
133	13.9	3.3	37.9	15.7	25.2	11.7
1246	13.4	5.8	40.1	13.0	23.8	17.7
1401	14.3	4.0	39.8	15.1	28.1	15.3
93	14.1	4.0	38.3	14.8	24.6	15.1
581	13.1	2.5	36.5	15.9	24.6	12.1
888	17.7	4.6	42.9	17.6	25.2	16.5
1417	14.7	5.3	43.4	13.5	23.5	19.6
1468	13.5	2.5	39.1	14.6	26.0	13.1
1438	12.4	1.4	42.9	18.2	27.5	15.3
615	14.8	4.2	43.2	15.1	27.2	19.2
788	14.2	5.2	40.5	13.1	26.0	20.1
12	14.7	3.2	36.9	11.7	25.9	10.9
45	13.7	3.6	42.7	16.1	23.7	15.6
679	13.4	5.7	32.7	11.3	22.5	11.6
564	17.6	6.1	36.5	13.1	25.3	13.7
1353	16.0	4.3	39.4	15.3	27.5	16.6
1398	15.2	4.6	42.3	11.7	26.1	17.7

*Hungarian millet.

each row, except one plant at each end, were pulled off by hand (10 plants as a general rule). Any plant adjacent to a missing hill was discarded. The height of the plants in inches, the number of stools per plant, the days to heading, the length of the longest head of each plant in inches, and the weight in grams per 10,000 kernels (unhulled) were obtained. Later, these were averaged and the results are summarized in Table 17.

SIMPLE CORRELATIONS

Each character was correlated with yield of plant and with the other factors in all possible combinations. Calculation of r was based on the method described in Wallace and Snedecor (10). Table 18 shows these correlation coefficients.

TABLE 18.—*Simple correlation coefficients for the different factors.*

	Height of plant	Days to heading	Length of head	Weight per 10,000 kernels	Yield of plant
Stooling	—.1610	—.0610	—.5441**	—.4862**	—.0514
Height of plant	———	.7421**	.5810**	.4447**	.5037**
Date of heading	———	———	.3980**	.3167*	.5345**
Length of head	———	———	———	.4211**	.4886**
Weight per 10,000 kernels	———	———	———	———	.4858**

A single asterisk indicates significant correlation and two asterisks indicate high significance. It can be seen from Table 18 that the yield of the plant is highly and positively correlated with all the factors named except number of stools which has a negative but insignificant correlation coefficient. Number of stools is negatively correlated with all the factors concerned, but only two, the correlation with length of head and with weight per 10,000 kernels, are significant. All other correlation coefficients between other factors are positive and significant.

MULTIPLE CORRELATION

The correlation between yield and the set of factors including stooling, height of plant, earliness, length of head, and weight of kernels was calculated, R being .7343. This is significant for when $n = 45$, the 5% level of significance is .460 and the 1% level .527. ($n = 44$ in our sample.) The relative effects of the five factors on yield of millet are shown in Table 19.

TABLE 19.—*Partial and zero order correlation coefficients of yield and other factors, together with standard regression coefficients.*

	Zero order correlation coefficient	Partial correlation coefficient	Standard regression coefficient
A, stooling	—.0514	.4185**	.4322
B, height of plant	.5037**	—.1211	—.1780
C, earliness	.5345**	.3034*	.3518
D, length of head	.4886**	.4409**	.4955
E, weight of 10,000 kernels	.4858**	.4679**	.4558

PARTIAL CORRELATION[4]

In order to study the association of each factor with yield independently of the variation of the other factors, partial correlation coefficients were calculated. These are also shown in Table 19.

Asterisks denote significance, as in Table 18. ($n = 44$ in our sample.) From these partial correlation coefficients thus calculated, we can conclude that yield of millet is really associated with weight of grain, length of head, number of stools per plant, and possibly earliness, after the other associations are taken into account. The height of plant, however, may have only an illusory relation to yield of millet, due to its association with other factors. The standard regression coefficients run almost parallel with the partial correlation coefficients.

It would mean, then, in selection work or selection of the parent for hybridization, that individual plants or varieties with good tillering, good length of head, heavy kernels, and fairly late in maturing are the ones to be selected. It should be kept in mind, however, that factors not studied here may play as important a rôle, if not more important, in determining yield. One must not be misled, therefore, by the results obtained from this experiment.

SUMMARY

In plat trials with millet, plats two rows wide and with the rows 15 feet in length proved most efficient. When land is not a limiting factor, however, plats of the same width but with rows 30 feet long, with a corresponding number of replications to the smaller plats, seemed to be the correct size and shape for these tests.

There seemed to be competition between varieties of millet. The competition coefficient was significantly and positively correlated with date of heading, but negatively with yield and insignificantly with the height of plant.

The closer the plants were set, the higher was the yield but less stooling per plant. By the use of analysis of variance, no significance was found in the yield of the different planting distances, i. e., 2, 4, 6, 8, and 10 inches apart, but there was a significant difference for the number of stools per plant for the different planting distances. The regression of yield on stooling was not significant.

Yield was correlated negatively with number of stools per plant, $r = -.0514$; but positively with the height of plant, $r = .5037$; days to heading, $r = .5345$; the length of head, $r = .4886$; and the weight of 10,000 kernels, $r = .4858$. The multiple correlation coefficient, $R = .7343$, was statistically significant. When the partial correlation coefficients were calculated, the yield of millet was correlated positively and significantly with the number of stools, length of head, and weight of 10,000 kernels, and possibly with the date of heading, but negatively and insignificantly with height of plant.

[4]Dr. C. Tu, Cotton Experiment Station, Hupeh Province, gave valuable suggestions for these calculations, and the authors wish to express their hearty gratitude.

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THE EFFECTS OF SODIUM CHLORIDE ON SOME TURF PLANTS AND SOILS[1]

V. T. STOUTEMYER AND F. B. SMITH[2]

RESEARCHES concerned with grasses for golf greens have not been developed until recently and the literature dealing with the effects of sodium chloride on the bent grasses and other turf plants commonly found on golf courses is rather meager. However, past studies on the salt tolerance of farm crops aid in understanding the problem.

Lipman, Davis, and West (6)[3] studied the sodium chloride tolerance of wheat, barley, and peas grown in nutrient solutions. A stimulating effect of sodium chloride was found for wheat up to concentrations of 8,000 p.p.m. and for barley up to 6,000 p.p.m., but increasing injury was noted with greater concentrations. The results obtained with peas were more variable but tended to show that above concentrations of 3,000 p.p.m. considerable injury was produced.

Yureva (11) obtained stimulation of tomato plants with concentrations of sodium chloride up to 0.2% of the dry weight of the soil.

Voelcker (10) found that applications of 500 pounds per acre of sodium chloride could be made without injurious effects to oats, wheat, lupines, and peas.

Breazeale (1) grew wheat in nutrient solutions and in soil. He found that the absorption of potassium was decreased when sodium was present in the solution used during the first period of growth before the plants were transferred to the soil. However, sodium assisted the absorption when the plants were grown in water cultures during both periods. The presence of sodium increased the transpiration and size of the plants even where there was an abundance of potassium.

Halket (3) found variations in salt tolerance between different species of plants and Hendry (5) found that varieties of legumes varied in their resistance to injury by sodium chloride in the soil.

Heald (4) summarized the literature on the effect of alkali salts on various crops, including the grasses and legumes His classification of alkali resistance of plants shows that such plants as salt bushes and salt grasses are able to grow in concentrations of about 1.5%, while such crops as wheat, emmer, Kafir, alfalfa, field peas, vetches, horse beans, and sweet clover, are able to exist only in concentrations above 0.4%.

Sodium chloride has been used occasionally to control weeds in asparagus. Evans (2) stated "as long ago as 1895 it was found at the Vermont Agricultural Experiment Station that the orange hawkweed, a serious pest in pastures and meadows, could be destroyed without serious injury to the grass by sowing salt over the land at the rate of 3000 pounds per acre." The possible application of this method of weed control in bent grass putting greens was suggested by the fact that these grasses are known to grow in seaside regions where the soils often contain a high content of sodium.

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[3]Figures in parenthesis refer to "Literature Cited", p. 23.

Monteith and Dahl (8) reported that too great concentrations of any soluble salts, including sodium chloride, have resulted in injury to turf on golf courses where salt spray from the sea or an abnormal type of water supply causes an accumulation in the soil.

According to a number of greenkeepers trained in Scotland, the application of rock salt to greens was a common practice on some of the historic golf courses of that country. It is also said that a well-known Scotch golf architect mixed rock salt in the top soil of newly constructed greens. The purposes which these treatments were intended to serve are not clear. Practices of this kind are apparently unknown to American greenkeepers. The following experiments with sodium chloride on a number of turf grasses were performed in order to determine whether there is any basis for such practices.

EXPERIMENTAL

METHODS OF PROCEDURE

The effect of sodium chloride and phosphorus on soils and on turf plants commonly found on putting greens was studied in a series of greenhouse and laboratory experiments. The Dickinson fine sandy loam was selected for use in this study and was sieved through a ¼-inch screen and placed in 1-gallon earthenware pots in the greenhouse.

The soils were treated in duplicate pots as follows:

1. Check.
2. Phosphorus equivalent to 400 pounds of superphosphate per acre.
3. Phosphorus equivalent to 800 pounds of superphosphate per acre.
4. Phosphorus equivalent to 400 pounds of superphosphate and 2,000 pounds per acre of sodium chloride.
5. 2,000 pounds per acre of sodium chloride.
6. 4,000 pounds per acre of sodium chloride.

The phosphorus and sodium were applied as dilute solutions of orthophosphoric acid and sodium chloride one month after the plants had been started in the pots. The use of phosphoric acid did not cause serious changes in the reaction of the soil even though the Dickinson fine sandy loam used was not well buffered. With the higher rate of application of phosphorus the immediate change in reaction was less than pH 1.0 and by the end of the growth period the reaction was almost back to that of the original soil. The slight increase in acidity produced by the phosphoric acid was considered preferable for the purpose of this experiment to the addition of a superphosphate fertilizer containing calcium sulfate.

The four grasses, seaside bent, metropolitan bent, Kentucky bluegrass, and Bermuda grass, and Dutch white clover, were used. Seven plants of each species used were started in each pot. The plants of Bermuda grass and the two bent grasses were started by planting uniform cuttings of the stolons about 1 inch long. The Kentucky bluegrass was started by taking uniform plants from sod. The plants of Dutch white clover were seedlings about 1 inch in height and having about six to eight well-developed leaves. The plants were watered as necessary with distilled water, usually two or three times a week. Wire stakes and cotton twine were used to support the stolons of the Bermuda grass and the bent grasses to prevent them from rooting on the surface of the bench. The Bermuda grass was grown in a greenhouse kept at a night temperature of about 60°F. The other

three grasses and the clover were grown in a greenhouse in which the night temperature was about 50°F and were on a ground bench.

The plants were harvested after growing 120 days from the starting in the pots and a growing period of 90 days after the treatment with phosphorus and sodium chloride. The plants were cut off at the soil level, placed in paper bags, and later dried to constant weight at 70°C. The dry weight of the tops was used as an indication of the response of the various plants to the different treatments. The data obtained are presented in Table 1 and Figs. 1 to 3.

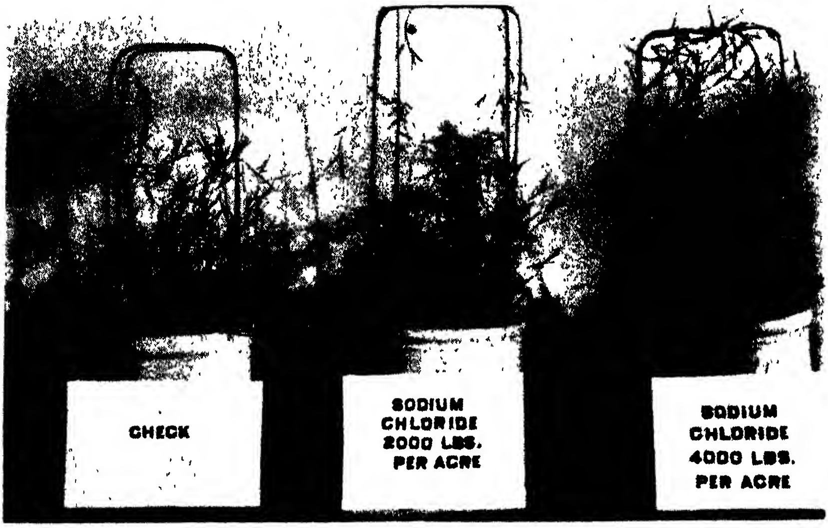

FIG. 1.—Effect of sodium chloride on metropolitan bent grass.

TABLE 1.—*Weight of plants in grams, oven-dry basis*

Treatment	Kentucky bluegrass	Metropolitan bent grass	Seaside bent grass	Bermuda grass	Dutch white clover
Check	1.93 1.55	5.47 5.08	11.91 12.19	8.12 9.15	6.06 4.88
400 pounds superphosphate per acre	2.43 1.74	8.11 8.05	10.00 9.51	8.95 7.16	6.93 7.44
800 pounds superphosphate per acre	2.99 3.30	5.86 6.72	9.23 14.00	8.71 12.86	8.09 8.59
400 pounds superphosphate and 2,000 pounds sodium chloride per acre	2.17 2.12	6.26 6.80	10.19 10.31	8.26 10.74	5.20 5.47
2,000 pounds sodium chloride per acre	2.11 1.96	5.49 5.35	10.26 9.09	8.23 8.59	3.57 4.34
4,000 pounds sodium chloride per acre	0.44 0.21	4.51 5.79	8.13 8.26	6.50 5.43	2.36 2.45

RESULTS

The data show that phosphorus was effective in increasing the yield of all crops used and that the higher application was more effective than the lower application in all cases, except the metropolitan bent grass. Sodium chloride brought about decreases in yield of all crops, except Kentucky bluegrass at the lower rate of appli-

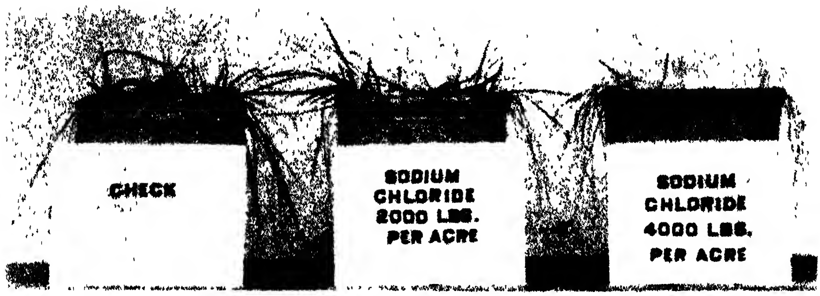

FIG. 2.—Effect of sodium chloride on Kentucky bluegrass.

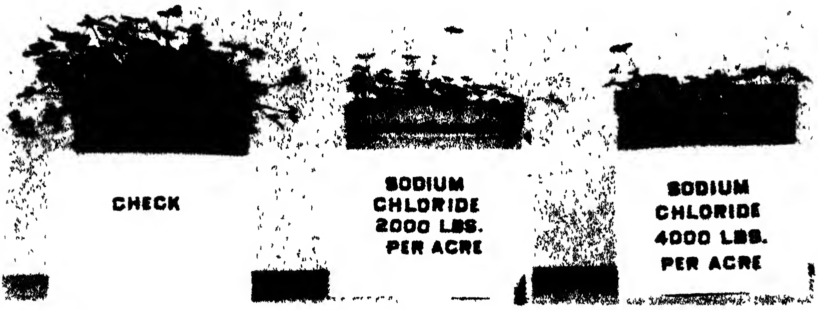

FIG. 3.—Effect of sodium chloride on Dutch white clover.

cation. The higher rate of application of sodium chloride was quite toxic to Kentucky bluegrass and the Dutch white clover. The Bermuda grass and the two bent grasses, especially the metropolitan bent, were more tolerant of the sodium chloride. Two thousand pounds per acre of sodium chloride in addition to 400 pounds of phosphorus brought about significant increases in yields of Kentucky bluegrass, seaside bent, and Bermuda grass over the 400 pounds of phosphorus.

The analysis of variance of the data, Table 2, shows that the differences obtained with the phosphorus and the sodium chloride were highly significant. The relatively large interaction mean square in comparison with the small experimental error indicates that the different plant species reacted differently to a given treatment.

TABLE 2.—*Analysis of variance.*

Source of variance	Degrees of freedom	Sums of squares	Mean square
Total	59	629.38	—
Within classes	30	21.39	0.713
Between means of treatments	5	74.49	14.898
Between means of plant species	4	459.91	114.977
Interaction	20	73.59	3.68

EFFECT OF TREATMENTS ON SOIL CONDITIONS

The soils were sampled from the pots in which metropolitan bent grass was grown after the grass was harvested for a determination of reaction, available phosphorus, and chlorides. Loss on ignition, dispersion, and exchangeable bases were also determined on the check soil and the soil treated with sodium chloride.

The pH was determined by the quinhydrone electrode. Available phosphorus was determined by the Truog (9) method and chlorides were determined by the official method. The procedure recommended by Middleton (7) was followed to determine the percentage dispersion and total exchangeable bases were determined by electrodialysis. The results obtained are presented in Table 3 and Fig. 4.

TABLE 3.—*Changes in soil treatments.*

Treatment	pH		P, p.p.m.	Cl, p.p.m.	Loss on ignition %	Dispersed %
	At beginning	At end				
Check	6.00	5.95	25.71	75.5	3.99	6.3
400 pounds superphosphate per acre	6.00	5.75	37.19	77.0	—	—
800 pounds superphosphate per acre	6.00	5.75	68.95	75.0	—	—
400 pounds superphosphate and 2,000 pounds sodium chloride per acre	6.00	5.90	39.61	98.0	—	—
2,000 pounds sodium chloride per acre	6.00	5.95	26.77	102.0	—	5.3
4,000 pounds sodium chloride per acre	6.00	5.95	24.15	121.5	4.06	6.8

The data in Table 3 show that the addition of phosphoric acid increased the acidity of the soil slightly, but the addition of sodium chloride did not bring about a change in the reaction. The soil treated with phosphorus equivalent to 400 pounds per acre and with sodium chloride contained slightly more soluble phosphorus than the soil treated with the phosphorus alone. The soil treated with 2,000 pounds of sodium chloride contained slightly more soluble phosphorus than the soil treated with the phosphorus alone. The soil treated with 2,000 pounds of sodium chloride contained slightly more soluble phosphorus than the check soil. Apparently the sodium chloride increased the solubility of the phosphorus or decreased the utilization of phosphorus by the metropolitan bent grass.

The addition of sodium chloride brought about an increase in the concentration of chlorides in the soil, but the loss on ignition and the percentage dispersed were not materially affected by this treatment. However, the total exchangeable bases of the soil were reduced by treatment with sodium chloride, the reduction in bases being about 4.0 milliequivalents with the 4,000 pounds per acre treatment of sodium chloride.

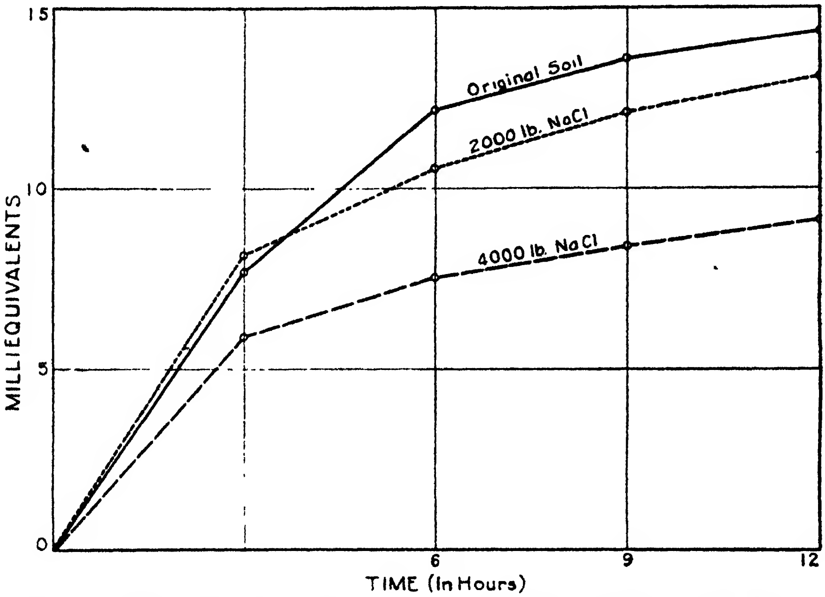

FIG. 4.—Effect of sodium chloride on the exchange capacity of Dickinson fine sandy loam.

PLAT EXPERIMENTS

In order to make a test of the effect of sodium chloride on grass turf under field conditions, eight plats each 10 feet square were located in a random arrangement over an area of metropolitan bent turf which was heavily and rather uniformly mixed with some Dutch white clover and Kentucky bluegrass. The top soil on this area had been prepared by composting and corresponded closely to some of the soil mixtures used for putting greens. The grass was maintained somewhat higher than putting green length during this experiment.

The following treatments were made with one replication of each:

1. Check.
2. Sodium chloride applied at the rate of 2,000 lbs. per acre.
3. Sodium chloride 4,000 lbs. per acre.
4. Sodium chloride 6,000 lbs. per acre.

The applications were made during the first week of May, 1935. In order to avoid burning, the salt was divided into two equal amounts and applied on two successive days. It was washed off the foliage and into the ground immediately with water from a garden hose. The

results were somewhat similar to those obtained in the greenhouse tests, except that the responses were obtained with lower concentrations of the salt. The white clover disappeared at once from all the salt-treated plats and was absent during the remainder of the season. Kentucky bluegrass, on the contrary, showed a marked stimulation on the 2,000- and 4,000-pound treated plats and did not disappear on any of the plats except those receiving 6,000 pounds per acre. The bent grass continued to make a normal growth under the 2,000- and 4,000-pound treatments. All turf plants showed injury on the plats receiving 6,000 pounds per acre.

DISCUSSION OF RESULTS

Highly significant differences were obtained with different treatments and with different plant species. Phosphorus was effective in stimulating the growth of all plants, especially Kentucky bluegrass and Dutch white clover. Sodium chloride at the rate of 4,000 pounds per acre was toxic to all plants, especially Kentucky bluegrass and Dutch white clover. The sodium chloride was less toxic to all plants when applied with phosphorus than when applied alone. The metropolitan bent grass was more tolerant of the sodium chloride than the other grasses.

The continued use of sodium chloride or the use of sodium chloride in any considerable amounts on the soil will bring about a replacement of bases with sodium. A soil complex saturated with sodium becomes dispersed or deflocculated after the removal of the excess salts by leaching and the resulting physical condition of the soil is poor.

The tests made on this soil after treatment with sodium chloride did not show any considerable change in the physical condition of the soil. However, the content of exchangeable bases was decreased. This decrease in the amount of exchangeable bases was probably caused by a replacement of bases in the organic exchange complex by sodium. The sodium-saturated organic complex is soluble and this would undoubtedly result in a decrease in the absorption complex. It is also possible that the exchange complex became more highly saturated with hydrogen, but this seems unlikely since the reaction of the soil was not changed. Since the loss on ignition was not decreased by the sodium chloride treatment and since the chloride content of the soil was increased, there was no considerable leaching of the soil by watering and there was an excess of sodium chloride present. The soil contained only 12.7% of silt and clay. The presence of the excess sodium chloride and the small amount of silt and clay explain the low percentage dispersion and the reason why the dispersion was not increased.

SUMMARY AND CONCLUSIONS

The effect of phosphorus and sodium chloride on some common turf plants and soils was studied in a series of greenhouse and laboratory experiments. Phosphorus stimulated the growth of the plants, but sodium chloride in the concentrations used was apparently toxic

in some cases and stimulative in others. The toxicity of the sodium chloride was decreased somewhat by the phosphoric acid.

Metropolitan bent grass was more tolerant to sodium chloride than Kentucky bluegrass, seaside bent grass, Bermuda grass, or Dutch white clover.

Highly significant differences in the effect of phosphorus and sodium chloride on the growth of the different plants were obtained. The total exchangeable base content of the soil was decreased by the treatment with sodium chloride. The results indicate that sodium chloride alone or in combination with phosphate fertilizers may be used on sandy soils for metropolitan and seaside bent grass. However, these experiments are preliminary in nature and further work with nitrogen and potassium fertilizers applied along with salt and on different soil types is necessary to permit of broader conclusions and such work would certainly be very desirable.

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A STUDY OF THE ASSOCIATION BETWEEN MEAN YIELDS AND STANDARD DEVIATIONS OF VARIETIES TESTED IN REPLICATED YIELD TRIALS[1]

F. R. IMMER[2]

SINCE the introduction of the "Analysis of Variance" by Fisher (2),[3] the randomized block and latin square arrangements of plats have enjoyed widespread use for comparative variety trials. The principles involved in these methods have, in the main, been tested with data from actual field experiments and found to be entirely valid for such data.

In 1931, Tedin (5), using published uniformity trial data, furnished experimental proof of Fisher's theoretical considerations regarding the necessity of a random arrangement of plats. Tedin demonstrated that with a random arrangement alone was it possible to obtain a valid estimate of error.

In 1933, Eden and Yates (1), using height measurements of wheat plants from different plats, made a practical test of the validity of Fisher's "Z" distribution for small samples drawn from a population which was definitely skew. They found that the "Z" distribution could be safely applied to such data. Fisher, Immer, and Tedin (3) had previously shown a negative skewness of plant height measurements taken from different plats, the plats with the taller plants being the least variable.

Another test of considerable importance, which can be made only with data from practical field trials, involves the determination of the independence of the means and standard deviations of individual varieties being compared. In comparative variety trials the number of strains, or varieties, to be tested is usually large and the number of replications must, of necessity, be small. This is true particularly of yield trials involving plant breeding material. In calculating an experimental error from such tests, it is assumed that the errors of the separate varieties are random sampling deviates from a population having the same errors, although their means differ. On this assumption is based the calculation of a generalized error for the entire experiment.

In 1928, Hayes and Immer (4) studied the relationship between mean yield and probable error of varieties of cereals tested in yield trials. They separated the varieties into three groups, *viz.*, those falling within the low, middle, and high third of the total range in yield of the varieties in the test. A separate probable error was calculated for each group. Such computations were made in eight separate tests. A general tendency for the errors to increase as yield increased was found. Comparing the intermediate group with the high-yield-

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[3]Figures in parenthesis refer to "Literature Cited", p. 27.

ing group, the high group had the higher error in three and a lower error in five of the eight experiments. In the comparison of the low and intermediate yield groups, however, the low group had the lower error in seven of the eight tests. It is with a further test of the association of mean yield and standard deviation of varieties in yield trials that the present paper is concerned.

MATERIALS AND METHODS

The data used consisted of bushel yields of corn, barley, oats, flax, and spring wheat strains and varieties tested in comparative yield trials by the Minnesota Agricultural Experiment Station. The tests were made at University Farm or at the branch stations located at Waseca, Morris, and Crookston. From 26 to 286 strains were involved in the different variety trials. In 14 of the 16 tests but three replicated plats of each strain were involved while four replicated plats were used in the other two tests. Since 1931 a random arrangement of plats within each replication series was used, while prior to 1931 the arrangement of the strains followed a systematic order.

The yield data for barley, oats, flax, and spring wheat were taken from rod row trials. The corn experiment consisted of plats of 12 hills each. The mean yield and standard deviation was calculated separately for each strain, or variety, within each test. The means and standard deviations of the separate strains were then correlated.

EXPERIMENTAL RESULTS

The correlation coefficients varied from + 0.2374 to — 0.3190. Only 5 of the 16 coefficients exceeded ± 0.10 and of these, 3 were positive and 2 negative.

In 1931, the same 62 strains of spring wheat were tested at University Farm, Waseca, Morris, and Crookston. The correlation coefficients in these four tests were all positive but less than 0.08. In 1932, the same 50 strains of spring wheat were tested at the same four stations. The correlation coefficients were — 0.2865 and — 0.0358 at University Farm and Morris, respectively, and + 0.2374 and + 0.2112 at Waseca and Crookston, respectively.

In the spring wheat tests referred to above the mean yield of each variety as an average of the four stations was correlated with the mean standard deviations of the same varieties for the same tests. The mean standard deviation was obtained by averaging the four variances of each variety and extracting the square root. The correlation coefficients between the mean yields of the strains as an average of the four stations (based on 12 plats each) and the mean standard deviations were — 0.0385 in 1931 and + 0.1713 in 1932.

The average correlation coefficient for the 16 tests given in Table 1 was obtained by transforming the values of r to Fisher's "Z" and calculating the weighted average of "Z" (2, page 191). The weighted average of "Z" was + 0.0373 ± 0.0311, a non-significant value The average value of r, by transformation from Z, was also + 0.0373. This average, based on 1,087 individual means and standard deviations, indicates definitely that within the range of yields obtained in these yield trials the standard deviations of the separate varieties tend to be independent of the mean yield of the varieties.

TABLE 1.—*The coefficients of correlation between means and standard deviations of strains and varieties tested in regular yield trials.*

Crop	Place grown	Year grown	Number of strains	Number of replications	Yield in bushels per acre		Correlation of means and standard deviations
					Mean	Range	
Corn	Waseca	1934	69	4	40.33	28.6–50.6	—.0227
Barley	University Farm	1928	66	4	56.41	41.8–68.4	—.3190
Barley	University Farm	1930	63	3	47.71	22.9–64.3	.0677
Barley	University Farm	1932	49	3	44.06	18.3–68.0	.1420
Oats	University Farm	1927	286	3	45.54	20.8–79.5	.0871
Flax	University Farm	1930	26	3	17.90	7.4–25.7	.0355
Flax	University Farm	1932	54	3	17.87	8.9–25.8	.0723
Spring wheat	Crookston	1934	26	3	36.45	31.2–41.7	.0949
Spring wheat*	University Farm	1931	62	3	16.60	10.5–20.6	.0419
Spring wheat*	Waseca	1931	62	3	25.26	18.1–30.6	.0755
Spring wheat*	Morris	1931	62	3	19.44	14.3–25.8	.0628
Spring wheat*	Crookston	1931	62	3	23.95	17.1–31.5	.0421
Spring wheat†	University Farm	1932	50	3	23.59	17.9–29.7	—.2865
Spring wheat†	Waseca	1932	50	3	23.65	15.7–30.7	.2374
Spring wheat†	Morris	1932	50	3	25.01	14.1–30.9	—.0358
Spring wheat†	Crookston	1932	50	3	22.09	18.0–29.3	.2112
Av							.0373

*The same 62 strains tested at the four stations.
†The same 50 strains tested at the four stations

CONCLUSIONS

It seems safe to conclude that in variety trials in which the range in yield is not too great, the assumption of independence of mean yields and standard deviations of the separate varieties is valid.

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THE INFLUENCE OF SEED INOCULATION UPON THE GROWTH OF BLACK LOCUST SEEDLINGS[1]

D. W. THORNE AND R. H. WALKER[2]

THE ability of black locust (*Robinia pseudoacacia*) to utilize atmospheric nitrogen, together with its spreading root system, makes it particularly adapted for soil conservation work. Mattoon (5)[3] reported that it is found widely distributed over the eastern half of the United States, but that its native home was probably in the Appalachian Mountains, including the outlying Piedmont region. He described it it as growing best on well-drained, neutral soils, and stated that it has been recommended for planting from the New England states south to Georgia and west to Texas, Missouri, and Illinois.

The important symbiotic relationship between the black locust and the legume root-nodule bacteria has been pointed out by a number of investigators. Nobbe, *et al.* (7) found that well-nodulated black locust seedlings produced a better vegetative growth than similar plants without nodules but which received either ammonium sulfate or calcium nitrate fertilizer. Mattoon (5) concluded that the presence of rhizobia in the roots of the locust seemed to give it a greater resistance toward attack by the locust borer. McIntyre and Jeffries (6) found that nodulated black locust trees increased the nitrogen content of the soil and made it more productive. They reported that the growth rate of catalpa and the amount of nitrogen in the soil decreased as the distance from the adjacent black locust plantings increased.

Some investigators in working with black locust have failed to take advantage of this symbiotic relationship. Ware (10), in a recent bulletin, reported that the locust grew but very poorly in the depleted soils of Alabama unless it received a complete fertilizer. He advocated about 0.4 pound per plant of a 2-8-4 fertilizer supplemented with about 0.1 pound of nitrate of soda. Accordingly it was concluded that the cost of establishing the locust satisfactorily makes it too costly to use in large scale reforestation programs, or for large-scale plantings on abandoned agricultural land. Throughout the report, however, no mention was made of the use of any bacterial inoculant for the plants. It appears reasonable that proper inoculation of the seed might make the use of much of the expensive fertilizer materials unnecessary and also insure a more vigorous continued growth of the plants

Many experiments have been conducted which have shown the advantage of seed inoculation in the growing of the common legumes. No papers are available, however, which report a similar study of the

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[3]Figures in parenthesis refer to "Literature Cited", p. 34.

black locust. The present extensive use of this plant makes such an investigation desirable.

The expediency of inoculating legumes when strains of the proper root-nodule bacteria are known to be present in the soil has long been a question of soil management regarding which very little data are available. The present investigation was confronted by such a situation and the results are of corresponding interest.

ISOLATION AND STUDY OF BLACK LOCUST ROOT-NODULE BACTERIA

The black locust organism used in this investigation was isolated from nodules collected from the roots of black locust trees occurring in central Iowa. Different strains were isolated on yeast extract-mannitol medium 79 of Fred and Waksman (3) upon which the organism grows readily and produces a heavy growth. The rapid, luxuriant growth produced, together with the ability of the organism to produce a typical serum zone in skimmed milk cultures, seems to justify placing it with the group of "fast growing" *Rhizobium*.

Maassen and Muller (4) and Burrill and Hansen (1) placed the black locust in a separate cross-inoculation group. In the present investigation their results were at least partially verified. Black locust seeds, sterilized with hydrogen peroxide (9), were planted in sterile pots of sand. These were inoculated in triplicate with each of the different strains of organisms isolated from the root-nodules of black locust and also with strains, known to be effective, representing each of the six recognized species of *Rhizobium* and also the organisms belonging to the dalea and cowpea cross-inoculation groups. The cultures of black locust organisms induced good nodulation on the black locust seedlings, but no nodules were produced by any of the other species of bacteria used.

Further tests also showed that the cultures of locust organisms employed would not produce nodules on plants representing any of the first eight cross-inoculation groups of legumes listed by Fred, Baldwin, and McCoy (2). No further tests were made to study the possibilities of cross inoculation with the plants of the several other groups of less common legumes.

INOCULATION OF BLACK LOCUST IN FIELD TRIALS

As a part of the federal soil conservation program, millions of black locust seedlings are being grown for use in checking soil erosion and for reforestation purposes. Three nurseries have been established in the near vicinity of Ames, Iowa, by the Soil Conservation Service and the Forest Service of the U. S. Dept. of Agriculture to produce locust seedlings for these purposes. The present investigation was carried out in cooperation with the workers at two of these nurseries.

Inasmuch as it has not been customary on these projects to inoculate any of the locust seed, a good opportunity was furnished for studying the results of such a practice. At the time of planting in the spring of 1935 the seeds used for part of the beds were inoculated with a culture of black locust root-nodule bacteria. After two months, the

size, appearance, and nitrogen content of the seedlings from the beds planted with inoculated seed in comparison with the same properties of plants from beds not planted with inoculated seed indicated distinct advantages from inoculation. This is of particular interest inasmuch as most of the plants throughout both nurseries bore some nodules as a result of the natural occurrence of the proper legume bacteria in the soil.

The black locust seeds were planted in beds 3 feet wide with spaces of 2 feet between beds. Field I was located on a recent alluvial deposit of a fine sandy loam over soil of the Wabash series, southeast of Ames near the Skunk River. The soil was low in organic matter and nitrogen, the nitrogen content being only 0.089%. The reaction was slightly alkaline, pH 7.69. In general, this soil may be rated as one of comparatively low fertility. The seeds used for the planting of three of the beds were inoculated with a culture of black locust root-nodule bacteria. The inoculated beds were located at random in the nursery.

Field II was located about 1 mile west of Ames on Clarion silt loam. The soil was of rather high fertility. The nitrogen content was 0.303% and the reaction slightly acid (pH 5.95). The seeds were planted in long beds as in field I. Three adjacent beds in the field were planted with inoculated seed and the remainder of the beds received no pure culture of the organisms.

Observations were made and data taken of the seedlings about 10 weeks after planting. It was found that nodules occurred on the plants throughout both fields regardless of whether or not the seed was inoculated. In spite of this fact, some rather distinct differences were observed. In field I the plants growing from the inoculated seed were easily distinguished from the other plants of the field. Their greater height, darker green color, and healthier appearance contrasted with the yellowish color and smaller size of the plants from the uninoculated seed made the beds of seedlings which had been inoculated easily discernible from some distance across the field. Such a contrast was not so evident in field II. All plants in this field had a deep green color and thrifty appearance and differences in height of the plants as a result of the two treatments were not so large.

In each of the two fields 100 plants were dug at random from the beds planted with inoculated seed. The same number of plants was similarly taken from the adjacent beds which were planted with the uninoculated seed. These four groups of plants were taken to the laboratory, washed free of soil, the total length of each plant recorded, and the length of the roots measured. The number of nodules per plant and the distance from the ground line to the first nodule were determined. These data were analyzed statistically. The mean and standard deviation were calculated for each group of measurements. The difference between the means for each determination on the seedlings which had received inoculum and those which had not was found and the degree of significance of these differences calculated. The data, including the results of the statistical analyses, are given in Table 1.

TABLE 1.—*Total plant lengths, root lengths, and the number and location of nodules on black locust seedlings growing from inoculated and non-inoculated seed.*

	Total plant length, cm		Root length, cm		Distance from soil line to first nodule, cm		Nodules per nodulated plant		Percentage of plants nodulated
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.	
Field I									
Inoculated ...	33.48	4.79	16.21	2.59	3.30	1.46	8.93	6.53	98.0
Not inoculated..	23.45	2.74	14.48	2.07	6.60	2.73	3.43	2.31	75.0
Mean difference.	10.03**	—	1.73	—	3.30**	—	5.50**	—	—
Field II									
Inoculated ..	38.00	7.95	15.94	3.77	1.92	0.56	9.76	5.54	100.0
Not inoculated..	30.00	4.85	14.32	2.98	3.66	2.52	4.57	2.91	94.0
Mean difference.	8.00	—	1.62	—	1.74*	—	5.19**	—	—

*Mean difference is significant.
**Mean difference is highly significant.

The greater significance in mean differences between inoculation and non-inoculation of seeds in field I as compared to field II corresponds to the generally accepted principles of legume inoculation. The higher nitrogen content of the soil of field II, presumably, made the plants of that field less dependent upon symbiosis with root-nodule bacteria than the plants of field I.

The groups of plants from which the data of Table 1 were taken were dried at 95°C and the dry weight of each group determined. The nitrogen content was determined by the Kjeldahl method. The resulting data are given in Table 2. The last column in the table records the percentage increase in total nitrogen in the plants receiving the bacterial cultures over those not receiving them. These data seem to indicate that inoculation provided the plants with a more efficient strain of organisms than was originally present in the soil. The evidence upon which this conclusion is based is more pronounced in the data from field I. This is to be expected for there the plants were forced to rely to a greater extent than in field II upon the symbiotic relationship with the legume organisms for their nitrogen supply.

The location of the nodules on the plants as a result of the inoculation and non-inoculation treatments was quite distinctive. The plants which had received the pure culture inoculum had more nodules per plant than those plants which did not receive it. The nodules were also located nearer to the tap root and the surface of the soil than the nodules which resulted from the native soil flora. Root systems representative of plants receiving each of the treatments are shown in Fig. 1.

Inasmuch as the black locust is being used rather generally for the reclamation of badly eroded land, a study of the growth of the seedlings on soil of low fertility seems of greater practical interest than its growth on more fertile soil. For this reason a more complete study was made of the seedlings of field I than of field II.

TABLE 2.—*Dry weights and nitrogen contents of black locust seedlings growing from inoculated and non-inoculated seed.*

	Nitrogen content of soil, %	Weight of 100 plants, grams	Nitrogen content of plants, %	Increase in total nitrogen from inoculation, %
		Field I		
Inoculated	0.089	23.43	3.06	297.2
Not inoculated	—	8.69	2.09	—
		Field II		
Inoculated	0.303	31.16	3.22	80.4
Not inoculated	—	21.15	2.63	—

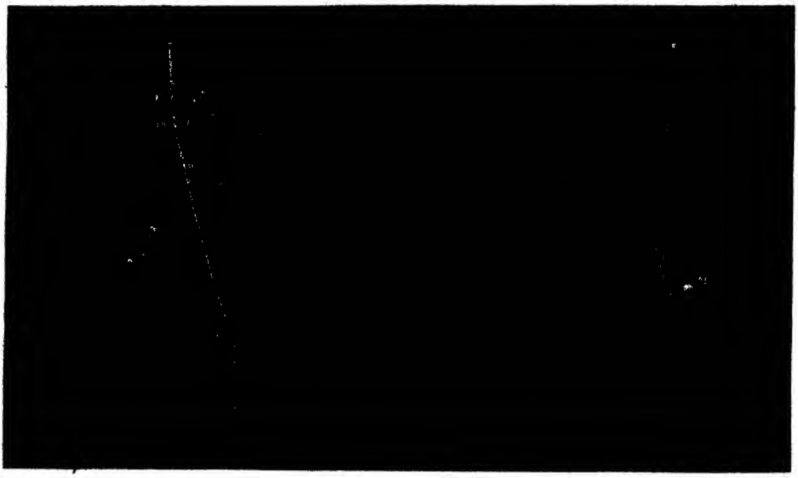

FIG. 1.—Nodulated roots of black locust seedlings.

The root on the left is representative of those grown from seed inoculated with a pure culture of the black locust root-nodule bacteria. The root on the right is representative of those grown from uninoculated seed.

At about the same time that the data of Table 1 were taken the number of plants per square foot of the nursery beds was determined for those beds which had received the pure culture inoculum and the adjacent beds which had not. This was accomplished by counting the number of plants within a circular hoop of known area dropped at random at 10 different places on each bed. Random measurements were also made of the heights of 100 plants of each bed upon which relative counts were made.

Shortly after the above data were collected the soil became very dry for a period of about a month. As a result large numbers of the apparently less vigorous seedlings which had not received any pure culture inoculum died. This made the beneficial effects of inoculation

appear even more prominent. To determine these differences, counts of plant stands were again made and the relative heights of the plants measured about 5 weeks after the first data were collected. The data for the plant heights and relative stands taken at the tenth and fifteenth weeks after planting were analyzed statistically. The results are shown in Table 3.

TABLE 3.—*The heights and stands of black locust seedlings growing from inoculated and non-inoculated seed planted in soil of low fertility (field I).*

	Seedlings at 10 weeks of age				Seedlings at 15 weeks of age			
	Plant length in centimeters		Plants per square foot		Plant height in centimeters		Plants per square foot	
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.
Inoculated	18.95	5.26	42.10	14.18	26.91	9.19	36.67	13.61
Not inoculated	12.21	3.10	40.82	13.57	17.59	4.69	26.86	12.17
Mean difference	6.74**	—	1.28	—	9.32**	—	9.81**	—

**Mean difference is highly significant.

It is notable that whereas at the tenth week there was no significant difference in the mean number of plants per square foot of bed between the inoculated and non-inoculated beds, 5 weeks later the mean difference was highly significant. The data indicated about a third more plants in the beds which had received the inoculum. The mean difference in plant height was further accentuated in the five additional weeks of growth.

DISCUSSION

It appears that the beneficial results from the inoculation of black locust under the conditions of these experiments might be accounted for by one or both of the following reasons: (a) Inoculation placed a larger number of the black locust root-nodule bacteria in contact with the seed, resulting in an earlier nodulation of the seedlings and a greater number of nodules per plant; or (b) the strain of organisms furnished in the pure culture inoculum was more efficient than the average of the strains naturally occurring in the soil. It has been shown by many investigators (2) that there is considerable variation among the strains of any species of *Rhizobium* in their ability to benefit the host plant.

Turner (8) and Ware (10) emphasized the possibilities of growing black locust on highly acid soils. They did not, however, take into consideration the possibilities of bacterial symbiosis. Black locust is usually planted in eroded or depleted soil for the purpose of checking erosion. It seems, therefore, very important that the plants be well inoculated in order to obtain the best growth on these poor soils and for the soil to derive the maximum benefit from the plants. Inasmuch as many of these soils are acid, the application of limestone would probably be necessary in such cases in order to realize the best results from inoculation.

SUMMARY

Experiments conducted in cooperation with the U. S. Dept. of Agriculture Soil Conservation Service and Forest Service nurseries in Iowa have shown the advantages of inoculation of black locust seeds. Although there was considerable nodulation of seedlings throughout the nurseries as a result of the presence of root-nodule bacteria in the soil, seedlings growing from the inoculated seed made better growth and fewer died during the summer months than did the seedlings which were infected only with the native microflora of the soil. The increase in total nitrogen content of the seedlings as a result of inoculation was 297.2% on a soil of low fertility and 80.4% on a soil of rather high fertility.

The nodules formed from pure culture inoculation were more numerous and were generally located much nearer the tap root of the host plant and closer to the surface of the soil than the nodules induced by the rhizobia occurring in the soil.

Two reasons for the beneficial results from inoculation were suggested, *viz.*, (a) inoculation resulted in a greater number of nodules located nearer the tap root of the plant; and (b) the strain of organisms supplied in the pure culture inoculum was more efficient than the average of the strains of this species originally present in the soil.

Cross inoculation tests showed that *Rh. meliloti*, *Rh. trifolii*, *Rh. leguminosarum*, *Rh. phaseoli*, *Rh. japonicum* from both soybeans and cowpeas, *Rh. lupini*, and the root-nodule bacteria of dalea (Wood's clover) were not capable of producing nodules on black locust roots. Furthermore, the black locust root-nodule bacteria were not capable of producing nodules on the leguminous symbionts of the above species of bacteria.

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ENVIRONMENTAL FACTORS AFFECTING SEED SETTING IN SUGAR BEETS[1]

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NEARLY all improvement in sugar beets has been accomplished through selection. The necessity for controlling the male as well as the female parentage in breeding heterozygous material is an accepted principle in crop improvement.

The purpose of these investigations was to find a method by which sugar beets could be successfully selfed for carrying on breeding investigations under Minnesota conditions, without using space isolations.

REVIEW OF LITERATURE

Through selection, strains and varieties of sugar beets with high sugar content have been developed. The sugar content of the high group selections by various German seed companies has been summarized by Becker-Dillingan (5).[3] In 1818 the sugar content was 6.0%. As a result of selection of desirable sized and shaped beets, the sugar content was 9.8% in 1848. By juice polarization the sugar content in 1888 was 13.7% and by pulp polarization selection the sugar content had increased to 21% by 1929-30. But Vilmorin (27), in 1856, reported finding individual beets with a sugar content of 21.0%.

Very little progress has been made in breeding sugar beets by the hybridization method. Roemer (16), in 1915, reported that beets degenerated when inbred Werner (28) obtained better results by selection. Strains of sugar beets inbred by Dudok Van Heel (8) generally yielded less than open-pollinated commercial seed although not because of degeneration.

Inbred strains obtained in Italy by Munerati (12) were less vigorous than normal beets, and crosses gave increased vigor. Darwin (6), in 1876, obtained increased vigor by crossing. By selection and inbreeding, Townsend (24) developed lines within three generations which would produce single germ seed balls in 75% of the cases. The "elites" reported by Sunderlin (23) obtained by hybridization of different lines or families gave better yields, as a rule, in comparison with strains obtained by mass selection.

When Shaw (19) planted beets 2 miles apart, the highest percentage of seed set was 2.29. Many of the plants were sterile.

Grocery bags were used successfully as isolators by Townsend and Rittue (25) in 1904. The seed balls with more than one flower were removed. This left only a small number of seed balls per bag. In this work bags were removed after pollination.

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[3]Figures in parenthesis refer to "Literature Cited", p. 50.

The investigation of Shaw (18) proved that thrips were important in pollinating sugar beets. He suggested the use of cotton around the stem and tying the bag tightly.

In 1926, Stewart and Tingey (22) used 2-pound grocery bags on about 75 beets. They state, "As a whole it may be said that sugar beets self-fertilized rather freely by this method under 1926 conditions at Logan". Stewart (21), in 1933, reported, "The production of seeds under bags has not been successful in several localities where tried."

The majority of the plants isolated with glassine bags by Reed (15) failed to produce seed and no plant produced more than 20 seeds.

Parchment isolators were used successfully by Nilsson (13, 14) at Svalöf. In 1916, 74% of the plants set seed under isolators. The branches were cut back leaving as many as 343 glomerules per isolator. When the branches were cut back leaving 10 or less glomerules, a much higher percentage of isolators with seed was obtained. In 1919 and 1920 two branches of related selfed plants were enclosed in the same isolator. As high as 98% of the isolators with less than 10 glomerules per branch set seed.

At Michigan, Down and Lavis (7) obtained no seed from plants isolated with parchment. The mother beets under tent isolators averaged 31.6 grams of seed per plant. Upon growing this seed it was found that, of the seed germinating, 41% had crossed with garden beets grown under adjacent tents. The data presented by Kohls and Down (11) indicated that inbreeding and selection of mother beets result, for a time at least, in an increase in the average production of seed per mother beet.

The tent isolators used by Vilmorin (26) were very satisfactory if the beets were planted early so that the plants flowered before hot weather. Tents with a window in the top used by Munerati (12) were satisfactory in Italy.

Archimovitch (1, 2, 3, 4), working at the Belaya Cerkov Plant Breeding Station in Ukraine, has used many types of tent isolators and parchment bag isolators. The wooden isolators were a total failure because of high humidity. Tent isolators. were very good, although they permitted some crossing. Under tent isolators he reports 82.4, 90.8, 87.2, and 72.2% of the plants with glomerules for 1926, 1927, 1928, and 1929, respectively, and with parchment isolators 5.5, 10.4, 28.4, 27.1, 31.8, and 22.6% of the isolators produced glomerules for 1925 to 1930, respectively.

MATERIALS AND METHODS

Desirable mother beets were selected from normal beets grown at Waseca, Minnesota, in 1930, 1931, and 1932. These were stored in sand during the winters at Waseca. The beets were planted in rows 3 feet 6 inches apart. In 1931, the beets were planted at Waseca May 8 and 9, at University Farm, St. Paul, May 7, and at Castle Danger, which is located 12 miles up the north shore of Lake Superior from Two Harbors, on May 18. Another planting was made at University Farm on May 15 for the purpose of studying the effect of aerating the isolators. In 1932 beets were planted at Waseca May 8; at University Farm April 28, May 10, and May 20; and at Castle Danger April 28 and May 11.

Beets were grown at Waseca and Castle Danger in 1933, but no results are given as the beets which were allowed to cross pollinate produced very little seed due to extreme heat and dry weather.

In order to determine whether beets responded differently to different isolators, many types were used. In 1931, 20 different types of parchment, kraft, cellophane,

pyralin, and black paper bags were used. In 1932, large, medium, and small bags of parchment, kraft, and cellophane were tested.

All parchment isolators were made of 30-pound weight parchment. The large parchment isolators used in 1931 were hand made, being 35 cm long, 15 cm wide, and 9 cm deep. The medium parchment isolators were of the type used in corn breeding at the University of Minnesota, being 30 cm long, 10 cm wide, and 6.5 cm deep. The small parchment isolators were the type of bags used for selfing rye, being 21 cm long and 6.5 cm wide.

The kraft grocery bags were of three sizes, the large ones being 34 cm long, 18 cm wide, and 11.5 cm deep. The medium kraft bags were 30 cm long, 15 cm wide, and 9 cm deep. The small kraft bags were 20 cm long, 10.5 cm wide, and 6 cm deep.

The large cellophane isolators used in 1931 were hand made, being 35 cm long, and 15 cm wide. The medium cellophane containers were hand made, being 25 cm long and 10 cm wide. In 1932, the cellophane isolators were made by folding and stapling the end of cellophane tubing. The large cellophane isolators were 12 cm wide and about 23 cm long. The medium cellophane isolators were 7.5 cm wide and about 23 cm long. The small cellophane isolators were 6.5 cm wide and about 21 cm long. The small cellophane isolators varied in thickness, the smallest bags being thinnest, and increased in weight to the heaviest.

All isolators were eyeletted at the top so that they could be tied to a bamboo or lath stake.

Either cotton or kapok was placed around the stems in 1931, before the isolators were firmly tied on at the base with heavy string. The kapok was somewhat more desirable because it did not mat when wet. In 1932 only kapok was used.

Isolators were placed on the branches a day or so before the lower glomerules on the branch opened. In beets the flowers, varying from 1 to 7, are formed in compact clusters known as glomerules.

At Waseca and University Farm in 1931 only the ends of the branches were clipped. This gave from one to several hundred glomerules per isolator. In addition, the plant sent out new branches under the isolator. It was observed at University Farm and Waseca that the branches in many of the isolators had grown so much and packed so tightly that mould grew and killed the portion of the plant under the isolator As a result at Castle Danger in 1931, and at all locations in 1932, most of the branches were cut back to leave from 10 to 50 glomerules enclosed within the isolator. Some had as high as 100 glomerules, and a few with only the ends clipped were used to check the results obtained at University Farm and Waseca in 1931.

Part of the isolators with branches which had been cut back were removed as soon as the stigmas had shown signs of having been pollinated.

In 1932, 32 plants grown at Waseca and Castle Danger were covered with cloth tent isolators just before the first flowers opened. Finely woven cloth was used to form a tent about 65 cm square and 160 cm high. The tent was fitted tightly over four poles and a lath framework. Some of the tents were provided with small cellophane windows for observation.

The temperature under different isolators and of the outside air was taken at University Farm for 13 days after the isolators were put on the beets in 1932. The air and tent isolator temperatures were also taken at Waseca.

In 1931, it was observed that glomerules were larger on branches which were cut back. Accordingly, in 1932, two main branches of as nearly equal size and

vigor as possible were labeled with string. One of the branches was cut back similar to those which were put under the isolators.

In order to lower the temperature and humidity, air was pumped through some bags of the late planting. The bags were put on in the usual manner except that a 1/16-inch hose and a small glass tube, used to let the air in and out, were wrapped with kapok and the isolators tightly tied with string. The air current coming out of the glass tubing was strong enough to blow out a lighted match held 3 inches from the end.

The isolators and branches from which the isolators had been removed were harvested and allowed to dry in a building. After the branches were thoroughly dry the glomerules were rubbed off between two corrugated rubber mats. The glomerules without embryos were crushed or the glomerule disc fell out exposing the ovary cavity.

The glomerules resulting from selfing were planted at Waseca as a part of the regular sugar beet breeding program.

EXPERIMENTAL RESULTS

TYPES OF ISOLATORS

The relative value of different types of isolators as a means of insuring selfed glomerules is given in Table 1. This table is sub-divided into two main groups consisting, first, of isolators where the branches were cut back and opened after pollination; and second, where the branches were cut back and the bags remained closed until harvest.

TABLE 1.—*The effect of different types of isolators upon the production of selfed beet glomerules.*

Type of isolators	Size of isolator	Number isolators		Percentage of isolators with glomerules	Average number glomerules per isolator with glomerules
		Used	Setting glomerules		
Branches Cut Back and Opened After Pollination					
Castle Danger, 1931					
Parchment	Large	5	2	40.0	11.0
	Medium	20	12	60.0	38.6
	Small	7	6	85.7	14.3
Kraft	Large	10	9	90.0	32.7
	Medium	2	2	100.0	30.0
	Small	7	5	71.4	23.4
Cellophane	Large	5	4	80.0	29.8
	Medium	13	12	92.3	40.9
University Farm, 1932					
Parchment	Large	2	0	0	0
	Medium	104	23	22.1	10.3
	Small	89	32	36.0	7.3
Kraft	Large	28	9	32.1	14.4
	Medium	45	26	57.8	10.6
	Small	29	12	41.4	8.1
Cellophane	Large	3	0	0	0
	Medium	9	0	0	0
	Small	10	5	50.0	4.4

TABLE 1.—*Continued.*

Type of isolator	Size of isolator	Number isolators: Used	Number isolators: Setting glomerules	Percentage of isolators with glomerules	Average number glomerules per isolator with glomerules
		Branches Cut Back and Opened After Pollination			
		Waseca, 1932			
Parchment	Large	15	1	6.7	45.0
	Medium	149	50	29.8	9.5
	Small	2	1	50.0	2.0
Kraft	Large	68	38	55.9	16.1
	Medium	75	33	44.0	7.5
	Small	2	1	50.0	26.0
Cellophane	Large	1	0	0	0
	Medium	36	20	55.6	13.4
	Small	2	1	50.0	1.0
		Castle Danger, 1932			
Parchment	Large	64	9	14.1	6.9
	Medium	111	25	22.5	13.4
	Small	105	42	40.0	11.1
Kraft	Large	71	33	46.5	15.0
	Medium	70	34	48.6	13.1
	Small	9	5	55.6	15.6
Cellophane	Large	2	0	0	0
	Medium	25	12	48.0	6.7
	Small	42	19	45.2	11.4
		All Locations (4 station years)			
Parchment	Large	86	12	14.0	7.6
	Medium	441	110	24.9	13.7
	Small	203	81	39.9	9.7
Kraft	Large	184	95	51.6	17.8
	Medium	192	95	49.5	10.8
	Small	47	23	48.9	13.8
Cellophane	Large	6	0	0	0
	Medium	70	32	45.7	10.0
	Small	54	25	46.3	9.6
		Branches Cut Back, Bags Not Opened After Pollination			
		Castle Danger, 1931			
Parchment	Large	3	0	0	0
	Medium	34	4	11.2	12.0
	Small	10	1	10.0	1.0
Kraft	Large	20	11	55.0	16.1
	Medium	5	2	40.0	24.0
	Small	9	3	33.3	12.7
Cellophane	Large	8	4	50.0	20.2
	Medium	17	3	17.6	5.0

TABLE 1.—*Concluded.*

Type of isolator	Size of isolator	Number isolators Used	Number isolators Setting glomerules	Percentage of isolators with glomerules	Average number glomerules per isolator with glomerules
Branches Cut Back, Bags Not Opened After Pollination					
University Farm, 1932					
Parchment	Large	2	0	0	0
	Medium	161	12	7.5	12.6
	Small	194	20	10.3	8.3
Kraft	Large	57	4	7.0	14.0
	Medium	51	10	19.6	8.3
	Small	45	10	22.2	12.6
Cellophane	Large	1	0	0	0
	Medium	4	0	0	0
	Small	11	3	27.3	3.0
Waseca, 1932					
Parchment	Large	19	1	5.3	2.0
	Medium	96	3	3.2	32.0
	Small	8	0	0	0
Kraft	Large	8	2	25.0	7.0
	Medium	11	1	9.1	14.0
	Small	13	0	0	0
Cellophane	Large	6	0	0	0
	Medium	31	2	6.5	2.5
	Small	1	0	0	0
Castle Danger, 1932					
Parchment	Large	15	0	0	0
	Medium	108	1	.9	45.0
	Small	102	5	4.9	3.0
Kraft	Large	17	2	11.8	18.5
	Medium	37	0	0	0
	Small	8	1	12.5	14.0
Cellophane	Large	6	0	0	0
	Medium	21	0	0	0
	Small	36	0	0	0
All Locations (4 station years)					
Parchment	Large	39	1	2.6	2.0
	Medium	399	20	5.0	17.0
	Small	314	26	8.3	7.0
Kraft	Large	116	23	19.8	14.6
	Medium	104	13	12.5	11.2
	Small	75	14	18.7	12.7
Cellophane	Large	13	0	0	0
	Medium	56	2	3.6	2.5
	Small	48	3	6.3	3.0

Kraft was the most satisfactory isolating material when the branches were cut back and the isolators opened after pollination. No consistent differences were obtained between different sizes of kraft isolators. The large kraft bags were not as suitable as the medium or small sizes because they were bulky and hard to tie on the beet stems. The large sizes were more easily destroyed by the wind.

When the branches were cut back and the isolators opened after pollination, the small parchment isolators produced a higher percentage with glomerules than did the large or medium parchment isolators at each location. The medium parchment isolators were more desirable than the larger size.

The large cellophane isolators used in 1932, which were made of heavier material than the other sizes, were a total failure. In all cases the branches died without any indications of glomerule formation. The branches under small cellophane isolators appeared more vigorous than the branches under medium cellophane when the isolators were removed. The cellophane isolators were very unsatisfactory when they were not opened after pollination.

The differences between isolators of different sizes for all locations (4 station years) were analyzed statistically by using the four-fold contingency test as given by Fisher (9). The X^2 values are given in Table 2.

TABLE 2.—*Values of X^2 for different sizes of isolators when the isolators were opened and unopened.*

Size of isolators	Type of isolator		
	Parchment	Kraft	Cellophane
Isolators Opened			
Large and medium	4.886	.174	3.048
Medium amd small	14.909	.004	.004
Large and small	18.636	.109	3.099
Isolators Unopened			
Large and medium	.467	2.151	.554
Medium and small	3.109	1.294	.145
Large and small	1.605	.039	.020

The X^2 values for the 5 and 1% points with 1 degree of freedom are 3.841 and 6.635, respectively. When the isolators were opened after pollination (see Table 1), the medium-sized parchment gave 24.9% of the isolators with glomerules. This was statistically superior to the large-sized parchment which produced glomerules under 14.0% of the isolators. The small parchment bags with 39.9% of the isolators containing glomerules were statistically better than either the medium or large parchment isolators. No significant differences were obtained between the different sizes of kraft isolators.

When the isolators were unopened no statistically significant differences were obtained, although there were some indications that small parchment was more desirable than medium parchment.

The results from large, medium, and small isolators of each kind were combined and are given in Table 3.

TABLE 3.—*The effect of parchment, kraft, and cellophane as isolating materials.*

Material and treatment	Number isolators		Percentage of isolators with glomerules
	Used	Setting glomerules	
Isolators Opened After Pollination			
Parchment	730	203	27.8
Kraft	423	213	50.4
Cellophane	130	57	43.8
Isolators Unopened			
Parchment	652	47	7.2
Kraft	295	50	16.9
Cellophane	117	5	4.3

When the isolators were opened after pollination, 50.4% of the kraft, 43.8% of the cellophane, and 27.8% of the parchment isolators produced glomerules. The unopened isolators were much poorer since 16.9% of the kraft, 7.2% of the parchment, and only 4 3% of the cellophane isolators produced glomerules. The X^2 test for independence in a four-fold table was used to determine the relative value of different types of isolating materials The data are given in Table 4.

TABLE 4.—*Value of X^2 for different types of isolating material when the bags were opened and unopened.*

Isolating material	Opened	Unopened
Parchment and kraft	59.032	23.341
Parchment and cellophane	13.457	.703
Kraft and cellophane	1.686	11.636

The kraft was significantly better isolating material than parchment whether the isolators were opened or not. The differences between cellophane and kraft were not significant when the isolators were opened, but highly significant when the isolators were unopened. The cellophane was more desirable than parchment when the isolators were opened but not different when the isolators were unopened.

Different sugar beet plants of commercial varieties are known to react very differently in their ability to set selfed seed. For this reason as many paired comparisons were made as possible of results when two types of isolators were used on the same plant. The data are given in Table 5.

In each comparison the kraft proved more satisfactory than parchment. The X^2 test was used to determine whether the differences were significant and an X^2 value of 25.985 was obtained. The relationship of kraft and parchment, when both isolators were on the same plant, is similar to that obtained when the isolators were on different plants.

TABLE 5.—*Comparisons of the percentage of the isolators containing selfed glomerules when kraft and parchment were on the same plant and when the isolators were opened after pollination.*

Place	Number comparisons	Isolators with glomerules			
		Kraft		Parchment	
		No.	%	No.	%
Castle Danger, 1931	10	9	90.0	5	50.0
University Farm, 1931	114	41	36.0	32	28.1
Waseca, 1931	140	76	54.3	49	35.0
Castle Danger, 1932	180	83	46.1	49	27.2
Total	444	209	47.1	135	30.4

Besides having more isolators with glomerules, kraft bags gave more glomerules per isolator than parchment. There were 78 comparisons on the same plant where glomerules were produced under kraft and parchment isolators. The kraft averaged 17.05 glomerules per isolator and the parchment 11.54 glomerules per isolator. The mean difference of 5.51 glomerules was statistically significant when analyzed by Student's method as applied to paired comparisons. The Z value was .627.

Kraft was the most desirable isolating material probably because of lower humidity and temperature within the isolator. The humidity within the pyralin isolators was very high. One could always find the kapok at the base of the isolator wet and drops of water on the inside. The moisture weakened the pyralin isolators causing them to break and nearly all were lost. The air within the large cellophane isolators, which were made of heavier material than the medium and light cellophane types, was also very humid. Moisture could be noticed occasionally inside the parchment isolators. The kraft isolators absorbed water readily during a rain and it may be assumed that they lost moisture from within as readily.

To study the humidity relationships within the isolators at University Farm, air was forced into different types, thus reducing humidity to the same level within the different isolators.

Seed production was very low in 1931 as too many glomerules were enclosed in each isolator. The ends of the branches were clipped in the same manner as used in the regular selfing plats. Only 10 of 64 isolators, or 15.6% of the isolators, contained glomerules. While this was not a good set of glomerules, it compared favorably with the regular selfing plat isolators which yielded only 1.7% of the isolators with glomerules.

Eight of the 14 plants used on the air line set some glomerules. This was 57.1% of the plants with glomerules under isolators. In the check plat, 4.1% of the plants produced glomerules under isolators.

The plants used in 1932 did not have nearly as many main stems arising from the crowns as the early and medium plantings in the regular selfing plat. The branches were cut back and only 10 to 50 glomerules were enclosed in each isolator.

Twenty-nine of the 58 isolators, or 50%, on the air line, when the isolators were removed after pollination, contained glomerules. The five plants on this same plat which received no air failed to produce glomerules. Glomerule production on the air line was somewhat higher than the results obtained in the regular plat studies in which 33.9% of the opened isolators formed glomerules.

In the regular plats, planted on April 29 and May 10, respectively, average yields of seed per plant were 103 grams and 72 grams. The plants used on the air line were planted on May 20 and gave an average seed production of 65 grams per plant.

Of the 12 plants used on the air line, 9 set glomerules under isolators. This number was equal to 75%, while 51% set glomerules in the regular selfing plat.

TEMPERATURE WITHIN ISOLATORS

The temperatures within 23 isolators of three different types were obtained at University Farm in 1932. The bulbs of the thermometers were held away from the plant and the sides of the isolator by the kapok which was around the stem of the plant and thermometer The temperatures were recorded at 8:00 a.m., 1:00 p.m., and 5:00 p.m

The isolators were placed on the tallest branches so as to prevent shading. The average temperatures in degrees Fahrenheit for 13 days after the isolators were placed on the plants were for kraft 74.7°, 82.7° and 81.0°; for parchment 73.3°, 83.7°, and 82.0°; for cellophane 81.8°, 88.5°, and 84.3°; and open air 71.0°, 79.1°, and 77.8° at 8:00 a.m., 1:00 p.m., and 5:00 p.m., respectively.

The significance of differences under different types of isolators was analyzed by the analysis of variance The mean squares are given in Table 6.

TABLE 6.—*The mean squares for the temperatures under different types of isolators at 8:00 a.m., 1:00 p.m., and 5:00 p.m.*

Variability for	Degrees freedom	8:00 a m.	1:00 p.m.	5:00 p m
Types of isolators	2	2,070.73	923.01	268.17
Within isolators:	22	195.00	25.92	71.70
Parchment	9	110.05	26.35	66.44
Kraft	7	188.87	13.12	54.76
Cellophane	6	329.58	40.22	99.26

Much variation was found between isolators of the same material. This variation was greatest at the 8:00 a.m. and smallest at the 1:00 p.m. readings. The variation between isolators of the same material is explained by the probable fact that if the sun shone on a flat side of the isolator it would warm up more rapidly than if it shone on a narrow side. At 1:00 p.m. when the sun shone more directly down on the isolators much less variation was obtained.

The types of isolators were very different in the light of the mean square for types of isolators divided by the mean for average variability within isolators. The cellophane isolators gave an average

temperature much higher than the kraft or parchment. The parchment isolators averaged 1 degree higher than kraft at 1:00 p.m. and 5:00 p.m.

TENT ISOLATORS

Tent isolators similar to those used by Munerati (12) and Archimovitch (3) were tried at Castle Danger and Waseca in 1932. The beets used in this study were isolated from the regular selfing plats. All of the beets were covered with tents. Individual plants were tented just before the first flowers opened. Of the 18 plants grown at Castle Danger, 7 set from 0.5 to 12 grams per plant, that is, 38.9% of the plants under tents set glomerules. This was almost identical with the results obtained at Castle Danger when the isolators were placed on the plants. At Waseca, 6 of the 14 plants under tents set glomerules. This was a percentage of 42.9 as contrasted with 51 when branch isolators were used. Seed setting under tents was much lower than reported by Archimovitch (3) who obtained glomerules on 72 to 90% of the plants placed under tent isolators.

The glomerules under the tents were very small, and in most cases each glomerule possessed but one small embryo. The stems of the plants were long, slender, and lacking in vigor. The plants developed very few new leaves.

The temperatures under the tents at Castle Danger at 8:00 a.m., 1:00 p.m., and 5:00 p.m. for the first 3 days after the plants were tented were 78.0°, 77.3°, and 75.7° F, respectively. At the same hours the temperatures of the atmosphere outside the tents were 66.5°, 69.3°, and 69.7°, respectively. The average temperatures under the tents at Waseca for 22 days after the tenting were 85.6° and 94.3° for 8:00 a.m., and 1:00 p.m., respectively. At the same hours the temperatures of the atmosphere outside of the tents was 81.3° and 89.8°, respectively. The humidity inside of the tents was high. The top of the soil in the tents at Castle Danger was wet and covered with algae.

EFFECT OF OPENING ISOLATORS AFTER POLLINATION

When the branches were cut back leaving 10 to 50 glomerules per isolator, the stigmas on all the flowers died within 10 to 20 days. The isolators could then be removed without danger of cross-pollination. If the branches are not cut back, the isolators cannot be removed because the glomerules flower progressively up the spike.

The effect of opening different types of isolators after pollination is given in Table 7.

In all cases there were substantial increases in percentage of isolators with glomerules when the isolators were opened after pollination. The increases were largest at Waseca and Castle Danger in 1932 when very few unopened isolators produced glomerules. The unopened parchment, kraft, and cellophane isolators at Waseca produced 3.3, 9.4, and 5.2%, respectively, of the isolators with glomerules compared with 31.3, 49.7, and 53.8%, respectively, of the opened isolators with glomerules. At Castle Danger, all 63 unopened cellophane isolators failed to produce seed, while 31 out of 69 opened cellophane isolators

TABLE 7.—*The effect of opening isolators of different types after pollination (branches cut back).*

Kind of isolators	Treatment	No. of isolators	Isolators with selfed glomerules	Percentage of isolators with selfed glomerules	Number glomerules per isolator with glomerules	Average number glomerules per isolator
		Castle Danger, 1931				
Parchment	Unopened	63	9	14.3	12.8	1.8
	Opened	38	23	60.5	29.0	17.6
Kraft	Unopened	63	26	41.3	19.2	7.9
	Opened	30	26	86.7	32.1	27.8
Cellophane	Unopened	55	15	27.3	25.0	6.8
	Opened	19	16	84.2	38.1	32.1
		University Farm, 1932				
Parchment	Unopened	358	39	10.8	9.6	1.05
	Opened	195	55	28.2	8.6	2.42
Kraft	Unopened	153	24	15.7	11.0	1.83
	Opened	102	47	46.1	10.7	4.93
Cellophane	Unopened	18	3	16.7	3.0	0.5
	Opened	19	5	26.3	4.4	1.16
		Waseca, 1932				
Parchment	Unopened	123	4	3.3	24.5	0.80
	Opened	166	52	31.3	10.0	3.14
Kraft	Unopened	32	3	9.4	9.3	0.88
	Opened	145	72	49.7	12.3	6.09
Cellophane	Unopened	38	2	5.2	2.5	0.13
	Opened	39	21	53.8	12.8	6.90
		Castle Danger, 1932				
Parchment	Unopened	225	6	2.7	10.0	0.27
	Opened	280	76	27.1	11.4	3.08
Kraft	Unopened	62	3	4.8	17.0	0.82
	Opened	150	72	48.0	14.2	6.79
Cellophane	Unopened	63	0	0	0	0
	Opened	69	31	44.9	9.6	4.30

produced glomerules. In 1931, at Castle Danger, a fair set of glomerules was obtained when the isolators were unopened, but the percentage of isolators with glomerules was more than doubled when the isolators were opened after pollination.

The number of isolators producing glomerules for opened and unopened bags was compared for different isolating materials and X^2 was used to determine whether the differences were significant (Table 8).

TABLE 8.—*X^2 values to determine if there is a significant difference as a result of opening bags on the numbers of plants setting glomerules.*

Place	Isolating material		
	Parchment	Kraft	Cellophane
Castle Danger, 1931	23.415	16.991	18.807
University Farm, 1932	26.814	28.137	.507
Waseca, 1932	35.641	17.419	21.686
Castle Danger, 1932	54.950	35.746	35.566

All of the X^2 values are highly significant except with cellophane at University Farm where only 39 isolators were used. This proves it was a very desirable practice, under these conditions, to remove the isolators after pollination. It provides embryos which have been fertilized with a better opportunity to develop.

EFFECT OF CUTTING BACK

Plants with isolators.—It was observed at University Farm and Waseca in 1931 that many of the isolators where only the ends of the branches were clipped were broken because there was not enough room for the plants to grow. Other branches were killed because of moisture and subsequent mold growth. Accordingly, at Castle Danger in 1931 and at all locations in 1932, most of the branches were cut back leaving 10 to 50 glomerules per isolator.

When the ends of the branches were clipped, 4 isolators out of 233 produced 19 glomerules at University Farm in 1931, 19 out of 254 produced 77 glomerules at Waseca in 1931, 1 out of 72 produced 50 glomerules at University Farm in 1932, and 47 isolators produced no glomerules at Castle Danger in 1932. On an average when the branches were cut back 10.6% of the isolators produced glomerules.

Open-pollinated plants.—To determine the effects of cutting back branches on open-pollinated beets, two branches as nearly alike as possible on the same plant were marked with string and one of the branches was pruned in the same manner as those previously described that were placed within isolators. The seed of the pruned branch and of an equal length on the untrimmed branch was harvested when the glomerules were mature. After the glomerules had thoroughly air dried, they were weighed on an analytical balance. At University Farm there were 34 pairs harvested. The mean weight per glomerule on the branches cut back was 52.43 milligrams, while the mean weight per glomerule on branches not cut back was only 34.90 milligrams. This gave an average increase of 17.53 milligrams per glomerule as a result of pruning the branch.

The cut back spikes and those not cut back were taken as a pair and the weight of glomerules produced was statistically analyzed by the analysis of variance as outlined by Fisher (9). Variance due to treatment divided by variance due to error was 162.62, a very significant result. The F value of 1% as given by Snedecor (20) for N_1 of 1 and N_2 of 30 is 7.56. The variation between plants was also significantly different, variance due to plants divided by error being 6.61. The F value of 1% for N_1 of 24 and N_2 of 30 was 2.47.

The effect of cutting back the branches on the production of open-pollinated glomerules for 35 pairs at Castle Danger in 1932 were very similar to those obtained at University Farm. The mean weight per glomerule on branches cut back was 64.65 milligrams, while the mean weight per glomerule on branches not cut back was only 45.62 milligrams, or an average increase of 19.03 milligrams per glomerule as a result of cutting back the branches.

Plants and treatment were highly significant. The variance due to plants divided by variance due to error was 5.66. The variance due to treatment divided by variance due to error was 119.54.

EFFECT OF LOCATION

The difference between locations was studied as the beets were selected from the same field each year. The summary for all locations is given in Table 9.

The best set of glomerules was obtained at Castle Danger in 1931 and the poorest at Castle Danger in 1932. The beets were on the same type of soil and located about the same distance from Lake Superior. The mean maximum temperature for the first 20 days after isolating was 68.3° and 74.7°F for 1931 and 1932, respectively. The higher temperature would increase the humidity of the atmosphere especially near the lake.

The X^2 test was used to determine whether glomerule formation was significantly different at the three locations and calculated values are given in Table 10.

In 1931, the production of selfed glomerules at Castle Danger was definitely superior to that at Waseca or at University Farm and also far superior to that at Castle Danger in 1932. In fact, in 1932, on the unopened isolators, more desirable results were obtained at University Farm than at Castle Danger. Temperatures at Castle Danger in 1932 were much higher than in 1931, as has been previously mentioned. These results make it appear very probable that cooler temperatures are desirable if high production of selfed seed is desired. While the data are not very conclusive they form a good basis for the conclusion that Castle Danger would usually be a more satisfactory location for the production of selfed seed of beets than either University Farm or Waseca.

SUMMARY

Tent isolators and isolators of different types and sizes of parchment, kraft, and cellophane were placed on mother beets grown at University Farm, Waseca, and Castle Danger, Minnesota.

When branches were cut back, leaving 10 to 30 glomerules per isolator and the isolator opened after all of the flowers had been pollinated, a satisfactory production of seed resulted. When the isolators were not opened after pollination much less seed was obtained. The branches isolated when only the ends were clipped produced practically no seed and most of the branches were killed or the isolators were broken.

Kraft isolators, whether opened or unopened, were more satisfactory for seed formation than parchment or cellophane.

TABLE 9.—*Summary of the number of isolators and percentage with selfed glomerules for different treatments, University Farm, Waseca, and Castle Danger, 1931 and 1932.*

Place	Year	Treatment	Number isolators	Isolators with selfed glomerules	Percentage of isolators with selfed glomerules	Number glomerules per isolator with glomerules	Av. number glomerules per isolator
University Farm . . .	1931	End clipped unopened	233	4	1.7	4.8	0.08
Waseca	1931	End clipped unopened	254	19	7.5	3.7	0.28
Castle Danger . . .	1931	End cut back unopened	232	54	23.3	18.7	4.35
		End cut back opened	111	76	68.5	34.4	23.59
Waseca.	1932	End cut back unopened	193	9	4.7	14.6	0.68
		End-cut back opened	350	145	41.4	11.5	4.78
University Farm	1932	End clipped unopened	72	1	1.4	50.0	0.69
		End cut back unopened	529	66	12.5	9.8	1.23
		End cut back opened	316	107	33.9	9.3	3.15
Castle Danger.	1932	End clipped unopened	47	0	0	0	0
		End cut back unopened	350	9	2.6	12.3	0.32
		End cut back opened	499	179	35.9	12.2	4.37
All locations and years		Ends clipped unopened	606	24	4.0	5.8	0.23
		Ends cut back unopened	1,304	138	10.6	13.8	1.46
		Ends cut back opened	1,276	507	39.7	14.7	5.85

TABLE 10.—*The value of X^2 for glomerule formation at the different locations when the isolators were opened and not opened after pollination.*

Locations	Isolators	
	Opened	Unopened
Castle Danger 1931 and University Farm 1932	40.174	14.159
Castle Danger 1931 and Waseca 1932	24.689	28.907
Castle Danger 1931 and Castle Danger 1932	39.658	61.958
University Farm 1932 and Waseca 1932	4.044	9.273
University Farm 1932 and Castle Danger 1932	.344	26.479
Waseca 1932 and Castle Danger 1932	2.692	1.698

X^2 for 5% 3.841; for 1% 6.635.

Tent isolators were not as satisfactory as branch isolators. The seeds obtained were very small. Temperature and humidity within the tents were very high and as a result the plants were weakened after being placed in tents.

Mother beets which were planted early were more satisfactory than later plantings when branch isolators were used. Early planted beets flowered when the temperature was cooler and produced many main branches arising from the crown.

When uncovered branches were cut back, the glomerules produced on them were larger than those obtained from similar branches not cut back. Cutting back the branches also permitted the removal of isolators after having been on the plants 2 to 3 weeks.

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THE NITROGEN, PHOSPHORUS, AND CALCIUM CONTENT OF THE COTTON PLANT AT PRE-BLOOMING TO EARLY BOLL STAGES OF GROWTH[1]

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DURING the season of 1933 a great deal of interest was manifested by farmers and others relative to the comparative composition of the cotton plant with other crops which are commonly used as feed for livestock. This was occasioned by the cotton acreage reduction program. The program became effective in central Oklahoma when the cotton plant was in the pre-bloom to early boll stages of development. Certain articles appeared at that time in farm papers relative to the feeding qualities of the plant. It is not the purpose of the writer to discuss this side of the question (1, 2, 7)[3], although observations would indicate that to be of much value in this respect the plant would have to be converted into silage, because of loss of leaves in curing, lack of palatability of the dried stalks, etc., but to present some data on the nitrogen, phosphorus, and calcium content of the plant at these stages of growth and on the boll growth at later stages of development.

Holley, *et al* (3) present data on the composition of the stems, leaves, and roots of cotton grown in culture solutions at approximately the stages of growth reported here. The general results for the N, P and Ca in the leaves and stems were of the same order of magnitude as found by the writer. Fraps (1) reports some rather extensive data on the mature cotton plant and its various parts. McHargue (7) has given data on the usual chemical composition of this plant along with elements such as Cu, Fe, Mn, Zn, and Na which are not so commonly reported.

White (9, 10) concluded that the cotton plant takes from the soil 34, 37, and 33% of its N, P, and Ca, respectively, from the time the seed sprouts until the first square is produced. During the period of growth of the first square to the first bloom it absorbs 32, 40, and 41% of its N, P, and Ca, respectively. From this period until the first open boll appears the percentages are 18, 18, and 10, respectively, and from here to maturity 16, 5, and 16%, respectively, are obtained for these three elements. Data are also given for the absorption of sulfur, potassium, and magnesium.

Hutchinson and Patterson (4) studied the composition of the cotton plant at various stages of development and report data on the roots, stems, leaves, and bolls of this plant. The need of the cotton plant for phosphoric acid, potash, lime, and magnesia is stressed by these workers, who further state that doubtless the proportion of available potash and phosphoric acid to available nitrogen in the soil should be large for proper fruit formation.

Kudrin (5) studied the composition of the cotton plant at five different stages of growth and observed that it absorbed the largest amount of nutrients from the soil between the bud (square) formation and bloom formation stages. He stated

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[3]Figures in parenthesis refer to "Literature Cited", p. 57.

further that at this time there was an increased absorption of Ca and N compared with P_2O_5 and Mg.

PROCEDURE AND DATA

On July 28, 1933, ten different fields of cotton on the Oklahoma Agricultural Experiment Station farm were sampled. Each sample consisted of two or three representative stalks taken from a small area in each location where the stand was uniform. The usual spacing was 10 to 12 inches in the row with rows 3.5 feet apart. Each of the stalks was separated into stem, leaves, and bolls and analyses were made on each separate division. No large bolls occurred on any of the stalks, although in case of locations 5 and 10, many small bolls appeared along with bolls approximately one-third developed. Squares of various sizes appeared on all stalks. The plants in locations 1, 2, 3, and 8 held only small squares, while those in locations 4 and 8 had larger squares as well. Plants 6b and 9b also carried large as well as small squares. The squares were included with the leaves in making the analyses. The green weight of each plant and its constituent parts were recorded immediately upon collection. Each sample was dried at 105° C for 48 hours, after which it was ground to pass through a 0.5-mm sieve. The analyses were made according to the A. O. A. C. methods, the regular Kjeldahl procedure without modification being used for total nitrogen.These data are presented in Tables 1 and 2.

For boll development, stalks were selected during the month of August, 1933, on which each stalk carried all of the various stages of boll development studied. The bracts were removed in preparing these samples for analysis. The results are given on the basis of oven-dry weight and are presented in Table 3 and 4.

DISCUSSION AND SUMMARY

No data are presented for the root system of the plant, but from the composition of the leaves, stem, and bolls it appears that there must be a rather pronounced intake of phosphorus by the plant as the squares develop and bolls are formed. While the average data show a slight decrease in the percentage of phosphorus found in the stems and in the leaves with plants having bolls over those not having bolls, the difference is small and is probably not significant in the cases presented. There can be no doubt, however, as to the decrease in the percentage of the plant's total phosphorus found in the leaves when the plant is developing bolls. This appears to be due to the increase in total weight of the plant by boll growth with only a rather limited withdrawal from the leaves. Since cotton may have newly formed squares to open bolls on the same plant at the same time, there must be present in the soil during this rather lengthy square and boll development period of the plant considerable available phosphorus. This explains, partially at least, why the more available phosphate fertilizers usually give best results with this crop.

Very much the same may be said of nitrogen, though the decrease in percentage of nitrogen in the leaves as bolls are forming is more than that for phosphorus. The type of nitrogen fertilizer to use would depend on the time of application. The usual practice of side dressing

TABLE 1.—*Composition of the cotton plant at pre-blooming to early boll stages of growth.*

Location	Plant	Percentage of nitrogen in					Percentage of calcium in					Percentage of phosphorus in				
		Leaves	Stems	Bolls	Whole plant, dry wt.	Whole plant, gr. wt.	Leaves	Stems	Bolls	Whole plant, dry wt.	Whole plant, gr. wt.	Leaves	Stems	Bolls	Whole plant, dry wt.	Whole plant, gr. wt.
1	a	3.80	1.33	—	3.037	0.831	3.39	0.75	—	2.571	0.703	0.286	0.115	—	0.233	0.064
	b	3.62	1.31	—	2.850	0.668	3.58	0.69	—	2.615	0.613	0.235	0.125	—	0.198	0.047
	c	3.62	1.15	—	2.910	0.583	3.91	0.51	—	2.939	0.588	0.230	0.101	—	0.193	0.039
2	a	3.66	1.35	—	2.890	0.652	3.59	0.76	—	2.640	0.595	0.267	0.159	—	0.231	0.052
	b	4.00	1.49	—	2.996	0.559	3.62	0.86	—	2.510	0.468	0.286	0.156	—	0.234	0.044
3	a	3.75	1.54	—	3.308	0.745	3.59	0.73	—	3.018	0.680	0.237	0.165	—	0.227	0.050
	b	3.81	1.45	—	2.023	0.593	3.70	0.83	—	2.738	0.537	0.238	0.165	—	0.214	0.042
4	a	3.41	1.14	—	2.843	0.569	3.59	0.47	—	2.809	0.562	0.273	0.098	—	0.229	0.046
	b	3.75	1.21	—	2.939	0.548	3.72	0.57	—	2.708	0.505	0.291	0.128	—	0.239	0.045
5	a	3.36	1.29	2.14	2.740	0.539	4.37	0.96	0.40	2.719	0.535	0.264	0.141	0.330	0.272	0.053
	b	3.75	1.32	2.37	2.975	0.526	4.48	1.11	0.34	2.780	0.492	0.286	0.144	0.336	0.277	0.049
6	a	3.44	1.05	3.03	2.690	0.564	3.80	0.85	0.41	2.509	0.472	0.236	0.123	0.162†	0.198	0.037
	b	3.59	1.44	—	2.904	0.614	4.00	0.76	—	2.969	0.628	0.216	0.126	—	0.187	0.040
7	a	3.66	1.65	—	2.810	0.526	3.52	0.97	—	2.439	0.456	0.235	0.159	—	0.203	0.038
	b	3.72	1.11	—	3.318	0.799	3.64	0.61	—	3.174	0.764	0.232	0.134	—	0.217	0.052
8	a	3.82	1.27	—	3.069	0.705	3.32	0.61	—	2.770	0.636	0.290	0.141	—	0.246	0.057
	b	3.82	1.37	—	3.394	0.710	3.46	0.57	—	2.957	0.618	0.259	0.113	—	0.234	0.049
9	a	3.09	1.46	2.27	2.641	0.611	3.42	0.64	0.15†	2.373	0.549	0.175	0.070	0.095†	0.142	0.033
	b	3.44	1.21	—	2.816	0.568	2.99	0.59	—	2.317	0.467	0.218	0.061	—	0.174	0.035
10*	a	2.75	0.84	2.06	2.114	0.412	4.22	0.54	0.29	2.171	0.423	0.224	0.064	0.201	0.182	0.035
	b	3.42	1.37	2.01	2.623	0.546	4.19	0.77	0.25	2.441	0.508	0.196	0.107	0.187	0.175	0.037
General Av. . .		3.58	1.30	2.31	2.882	0.609	3.72	0.72	0.31	2.675	0.562	0.246	0.123	0.218	0.214	0.045
Av. plants without bolls		3.70	1.33		3.007	0.615	3.57	0.69		2.745	0.588	0.253	0.130		0.217	0.047
Av. plants with bolls. . . .		3.03	1.22	2.31	2.631	0.533	4.05	0.81	0.31	2.499	0.497	0.230	0.108	0.218	0.208	0.041

*Location 10 bottom land soil; all others upland soil.

†Probably not accurate on account of extremely small sample. See also Table 3 where large samples were available.

TABLE 2.—*Ratio studies concerning leaves, stems, and bolls.*

Location	Plant	Percentage of total content in the leaves			Weight of dry matter, grams		
		N	P	Ca	Leaves	Stems	Bolls
1	a	86.46	84.95	91.04	19.0	8.5	0
	b	84.68	78.99	91.25	25.0	12.5	0
	c	88.77	85.06	95.03	10.0	4.0	0
2	a	84.43	77.05	90.40	23.0	11.5	0
	b	80.11	73.33	86.28	15.0	10.0	0
3	a	90.69	85.18	95.16	20.0	5.0	0
	b	84.01	74.26	89.86	14.0	7.0	0
4	a	89.97	89.31	95.84	15.0	5.0	0
	b	86.86	82.91	93.28	16.0	7.5	0
5	a	69.74	55.28	91.43	31.0	6.0	17.5
	b	70.59	57.76	83.04	28.0	8.0	14.0
6	a	74.59	69.55	88.11	14.0	7.0	3.0
	b	84.28	78.60	91.87	15.0	7.0	0
7	a	75.15	66.83	83.26	7.5	5.5	0
	b	94.85	90.50	97.02	11.0	2.0	0
8	a	87.88	83.15	84.35	12.0	5.0	0
	b	92.98	91.59	96.65	19.0	4.0	0
9	a	76.05	80.11	93.67	13.0	4.0	3.0
	b	87.97	90.17	92.93	9.0	3.5	0
10	a	55.25	57.25	85.26	42.5	20.0	29.0
	b	68.94	59.15	90.74	46.0	18.0	23.0
General av.		81.63	76.71	90.78			
Av. plants without bolls		86.61	82.12	91.61			
Av. plants with bolls		69.19	63.18	88.71			

TABLE 3.—*A summary of the analyses of cotton bolls at various stages of development.*

Stage of growth	N %	P %	Ca %
Practically mature bolls	2.40	0.223	0.271
¾ mature bolls	2.64	0.268	0.284
½ mature bolls	2.56	0.249	0.326
¼ mature bolls	2.82	0.306	0.598
⅛ mature bolls	3.57	0.390	1.255
Bloom*	3.69	0.448	1.200
Pre-bloom†	4.56	0.533	1.568

*Includes the blossom but not the bracts.
†Includes only the bud without bracts.

with such available forms as nitrate of soda after chopping or the application of mixed fertilizers containing various types of nitrogen

TABLE 4.—*A summary of the analyses of the burr and the lint and seed.*

Stage of growth	N %	P %	Ca %
Burrs			
Practically mature (bolls not open)	1.98	0.115	0.359
¾ mature	2.34	0.150	0.449
½ mature	2.60	0.179	0.607
¼ mature	2.60	0.245	0.742
⅛ mature	3.42	0.357	1.580
Seed and Lint			
From practically mature bolls	2.04	0.248	0.188
From ¾ mature bolls	1.98	0.272	0.159
From ½ mature bolls	2.57	0.278	0.194
From ¼ mature bolls	2.51	0.269	0.179
From ⅛ mature bolls	3.73	0.415	0.201

carriers at or near planting time, would appear to be confirmed as being good practices on soils not capable of supplying the necessary plant food from the standpoint of intake or need of this plant food element, by the cotton plant during the square development-boll formation period of growth. If boll weevil infestation occurs, bolls may not be formed or developed. Where this is the case the heavy nitrogen consumption that ordinarily goes into the bolls is utilized by the plant to produce excessive vegetative growth.

The calcium content of the leaves appears to increase some as squares and bolls are produced by the plant. The increase is not quite sufficient to maintain the percentage composition for the whole plant when the bolls are making rapid growth since the bolls are relatively low in this element soon after they develop any appreciable size. However, since the percentage of calcium is maintained or increased by the leaves and stems of the plant during this period of rapid vegetative growth, the intake of calcium is considerable at this time and is accounted for in the increased vegetative growth and that present in the bolls. The seed and lint taken together are relatively low in calcium compared with that in the burr. The results secured by the writer for the nearly mature unopen burrs are lower than those secured by Fraps (1) and some other workers (6, 8) for mature open burrs.

Summarizing, it appears that there is a considerable absorption of calcium by the cotton plant at this period of development, but that most of it is concerned with the vegetative part of the plant remaining in the leaves and stems. The intake of nitrogen and phosphorus is also great at this time, and while a considerable amount of each is required for the rather extensive vegetative growth taking place, boll development accounts for a large proportion of the nitrogen and phosphorus in the mature plant.

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LENGTH OF EXPOSURE TO LIGHT IN RELATION TO PLANT GROWTH IN RICE[1]

CHIEN-LIANG PAN[2]

MANY studies have been made with different crops on length of exposure to light in relation to time of maturity. Garner and Allard (4)[3] first introduced the term "photoperiodism" to designate the response of plants to the relative length of day and night. He classified crop plants into two groups, namely, long-day types which respond to long days and short-day types which blossom normally in the short-day season. Tincker (9) found by exposing plants of soybeans, chrysanthemums, and runner beans to light less than the normal length of day that flowering was accelerated. On the other hand, the flowering period of red clover, Gramineae, and radish was retarded. Garner (5) found with plants that responded to a long day that a 6-hour alternation of light and darkness hastened the appearance of blossoms. In the short-day varieties of soybeans, flowering was decidedly delayed by 6-hour and 4-hour alternations. Garner (3) reported that Biloxi soybeans blossomed in 26 days when they were allowed to receive 7 hours of light daily, while plants of the same variety exposed to light throughout the day required 110 days to flower Similar results were obtained from wild asters, lima beans, the Peking soybean, and the common ragweed Evans (2) reported that timothy growing at Savannah, Georgia, bloomed much later than when it was grown at Fairbanks, Alaska. This was due to the fact that the length of day is gradually increased from south to north during the time just a short period after spring growth

Harrington (6) reported that in wheat, barley, oats, and rye varying intensities of light gave the same effect on plant growth as a modification in duration of light. The stronger the intensity of light, the fewer the days required from seeding to heading Moderate intensity of light was needed in order to produce a crop with tall plants. Shirley (8) reported that with decreasing light intensity buckwheat, sunflower, geum, redwood, and galinsoga tended to increase their height, but all plants flowered approximately at the same time under all light intensities Garner and Allard (4) found that, although the length of daily exposure to light may exert a controlling influence on the attainment of the reproductive stage, light intensity is not a factor of importance. Adams (1) found that the rate of growth was more rapid at first in the plants exposed to a diminished supply of light, but plants constantly exposed to light for a greater number of hours ultimately attained the greater height.

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[1]Contribution from the Department of Crop Breeding of the Provincial Experimental Station, Chekiang, China. Paper read at the annual meeting of the American Society of Agronomy, Chicago, Ill., December 6, 1935. Received for publication November 25, 1935.

[2]Formerly Junior Agronomist. The author wishes to express his deep appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, and to Dr. H. K. Wilson, Associate Professor of Agronomy, University of Minnesota, for advice regarding the interpretation of data and preparation of this manuscript.

[3]Numbers in parenthesis refer to "Literature Cited", p. 63.

Electrical illumination in the case of hemp had a retarding effect on both the height and weight of the plants. Flowering of soybeans was entirely prevented by continuous exposure to light in the day time followed by 5 hours of electrical illumination in the night. Ramaley (7) reported that increasing the length of day by using artificial light accelerated the blossoming period of eight species of Caryophyllaceous and some species of Agrostemma, Dianthus, and Viscaria. Rice has not been extensively studied, the present paper summarizing a preliminary experiment.

MATERIALS AND METHODS

The material used in this study consisted of six varieties of rice with different growing periods when grown under natural conditions. Ten seeds of each variety were sown per pot on April 19, 1932, and thinned to five plants per pot 10 days after germination. None of the treatments was replicated.

The length of period that the plants were exposed to light was artificially controlled. On account of lack of equipment, the use of artificial light in order to lengthen the period of exposure was not studied, but the normal light period was shortened by covering the pots with a black cloth cover. The different treatments made are described as follows:

Treatment A, Check trials, growing plants under normal conditions.

Treatment B, Covering the pots at 6 p.m. to 6 a.m., the next morning exposing the plants to light for 12 hours per day.

Treatment C, Exposing the plants to light from 8 a.m. to 5 p.m., making a period of 9 hours.

Treatment D, Exposing the plants for 6 hours from 9 a.m. to 3 p.m.

The treatments mentioned were started on June 15. Number of culms per pot was recorded. The tallest plant in each pot was measured. The date of heading was studied by counting the number of heads on and after the day on which the first head was produced.

EXPERIMENTAL DATA

NUMBER OF CULMS PER PLANT

Table 1 shows that the early and medium maturing varieties, as 1781, 2407, 4461, and 3921, produced fewer culms when grown under

TABLE 1.—*The effect of length of exposure upon the number of culms produced per plant.*

Varieties	Treatments							
	A (check)*		B (12 hrs.)		C (9 hrs.)		D (6 hrs.)	
	No.	%	No.	%	No.	%	No.	%
1781 (E)†	47	100	32	68.08	32	68.08	24	51.06
2407 (E)	39	100	31	79.49	33	84.62	28	71.79
4461 (M)	26	100	22	84.62	14	53.85	20	76.92
3921 (M)	37	100	23	62.16	22	59.46	23	62.16
9549 (L)	18	100	22	122.22	19	105.56	21	116.67
9554 (L)	20	100	22	110.00	20	100.00	24	120.00

*Considering the check pot as 100%.
†EML are the letters used to designate early, medium, and late maturing rice.

short-day treatments than the plants of the same varieties when grown under natural conditions. In the case of late-maturing varieties, the plants treated by reducing the length of light showed a slight increase in number of culms, although the difference may be within the limits of experimental error.

The results with the early- and medium-maturing varieties may be expected because shortening the period of exposure naturally reduces plant growth; as a result, the stooling ability of the plants probably was decreased.

It is difficult to explain the results obtained with the late-maturing varieties. Speculation of any sort is unwarranted before further confirmation is obtained.

HEIGHT OF PLANT

Five plants were grown per pot. The height of each plant was measured from the soil surface to the top of the plant, the measurement being made in centimeters. The average of these five measurements was considered as the average height of these five plants for the treatment under which they were grown. The results are given in Table 2.

TABLE 2.—*The effect of length of exposure on the height of plant.*

Variety	Treatments							
	Check*		12 hours		9 hours		6 hours	
	Height, cm	%	Height, cm	%	Height, cm	%	Height, cm	%
1781.	82.4	100.00	83.7	101.58	97.0	117.72	90.0	109.22
2407.	84.0	100.00	82.9	98.69	90.9	108.21	83.0	98.81
4461.	85.9	100.00	98.1	114.20	94.7	110.24	96.4	112.22
3921.	66.9	100.00	91.4	136.62	86.0	128.55	89.1	133.18
9549	71.8	100.00	76.5	106.54	74.9	104.32	72.9	101.53
9554.	65.6	100.00	70.6	107.62	71.1	108.38	74.9	114.18
Av.	76.1	100.00	83.9	110.25	85.8	112.75	84.4	110.91

*Check considered as 100.

As an average of six varieties, the plants exposed 12 hours were about 10% taller than the check plants, but no significant difference was obtained between plants grown under 6, 9, and 12 hours of exposure to light treatments. The data clearly indicate that reducing the length of exposure increased the height of the plants.

DATE OF HEADING

Rice varieties differ considerably in earliness of maturity. The early-season varieties usually mature in early August, while the late-season varieties commonly ripen in late October; consequently, hybridization between early- and late-season varieties is difficult when the plants are grown in the field. Learning how to change the

period of maturity by artificial means to enable one to cross a late-maturing variety with an early one is of utmost importance. Photoperiodism is believed to have its greatest effect on the date of maturity. The data relating to maturity are given in Table 3.

TABLE 3.—*Number of days from treatment to first heading in relation to length of day with early, medium, and late varieties of rice.*

Varieties	Treatments			
	Check	12 hours	9 hours	6 hours
1781	55	53	60	48
2407	55	47	43	42
4461	64	48	51	42
3921	75	55	49	55
9549	68	42	45	39
9554	71	42	43	42
Av.	64.7	47.8	48.5	44.7

There was considerable variation between these six varieties in the requirements of number of days from treatment to the appearance of first head Variety 1781 required 48 days to produce the first head when treated with 6 hours of light per day, while the check plants of the same variety did not shoot until seven days later. The other five varieties reacted in a similar manner. As an average of the six varieties, the check plants required 64.7 days, while the plants exposed to 12, 9, and 6 hours of light per day required 47.8, 48.5, and 44.7 days, respectively. This shows that shortening the length of exposure hastened the period of maturity.

The number of spikes per pot was recorded each 5-day period after the time when the first head appeared in each pot. The data are given in Table 4.

Check plants of varieties 1781 and 2407 produced their first spikes about 10 days earlier than the check plants of variety 4461, and 15 to 20 days earlier than check pots of varieties 3921, 9549 and 9554. On the contrary, the plants of varieties 9554 and 9549 when treated with 6 hours of light per day produced their first head 45 days after the treatment, while varieties 4461, 2407, and 1781, similarly treated, required about 45 to 55 days from treatment to first heading. In other words, reducing the length of time that the plants were exposed to light hastened the period of maturity more in the late-maturing varieties than in the early ones.

Such results can be interpreted as it was previously, *viz.*, that the late-maturing variety usually matures in late October. The length of day in October at Hangchow is very short; consequently, shortening the length of day during the early growing season by artificial means will dispose the plants to the condition which is normally favorable for its maturity. On the other hand, the early-maturing varieties commonly ripen in the time when the length of day is very long; therefore, cutting down the length of day will not have any great effect on time of flowering. However, when the duration of light is shortened,

TABLE 4.—*The effect of length of exposure upon the number of spikes produced per pot in number of days after treatment.*

Variety	Treatment	Number of days after treatment								
		40	45	50	55	60	65	70	75	80
1781	Check pot			—	1	1	30	38	41	42
	12 hours			—	2	11	26	26	27	28
	9 hours			—	6	1	27	29	29	29
	6 hours			1	3	6	13	19	26	27
2407	Check pot		—	—	1	5	19	26	36	36
	12 hours		—	5	9	13	26	27	28	28
	9 hours		2	6	13	15	24	28	31	31
	6 hours		4	12	13	17	24	29	36	37
4461	Check pot		—	—	—	—	5	16	19	20
	12 hours		—	1	9	13	20	20	21	21
	9 hours				4	7	14	14	15	15
	6 hours		1	4	11	14	17	20	26	30
3921	Check pot								1	3
	12 hours		—	—	1	4	18	20	20	22
	9 hours			2	3	4	15	20	21	21
	6 hours			—	2	6	14	16	17	18
9549	Check pot							3	13	16
	12 hours	—	14	19	19	24	27	35	41	55
	9 hours	—	1	12	12	12	17	28	28	28
	6 hours	2	11	12	14	15	24	25	40	41
9554	Check pot								12	16
	12 hours	—	11	17	17	19	37	41	66	67
	9 hours	—	2	13	16	16	21	23	32	37
	6 hours	1	4	9	9	12	15	18	25	26

the growth of plants becomes weaker. This may hasten the blossoming period, because reproduction will take place as soon as the vegetative growth is nearly completed.

SUMMARY

A preliminary study was made to determine the relationship between length of exposure to light and plant growth in rice. The length of day was artificially shortened by covering the plants with a black cloth. Four lengths of exposure to light were made, *viz.*, check, 12 hours, 9 hours, and 6 hours.

Stooling ability of the plant was directly influenced by the length of exposure. A marked decrease in number of culms per pot was observed when the plants were grown under short day treatments.

Height of plant was increased when the period of exposure was decreased.

The period of maturity was hastened by shortening the length of day. The effect was much greater with late-maturing varieties than with varieties that normally matured early in the season.

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REGISTRATION OF STANDARD WHEAT VARIETIES, II[1]

J. ALLEN CLARK[2]

FOLLOWING the publication in 1922 of the Classification of American Wheat Varieties (U. S. Dept. Agr. Bul. 1074), the American Society of Agronomy approved the classification and the Committee on Varietal Standardization suggested registration of all varieties described therein. The subcommittee for the registration of wheat varieties[3], acting on this suggestion, listed the official names of the varieties, in classified order, and assigned registration numbers to 229 of them. These were registered as standard varieties.

A revision of the above-mentioned classification was published in 1935 as U. S. Dept. Agr. Tech. Bul. 459 entitled "Classification of Wheat Varieties Grown in the United States". In this revised bulletin, 77 new varieties have been described. Forty-two of these have been registered by the Society as improved varieties during the past 13 years, and certificates of registration have been issued to the breeders The remaining 35 varieties have been approved by the Committee of Varietal Standardization and Registration for registration as standard varieties.

The official names and registration numbers for these 35 varieties are given below:

Varietal Name	Reg. No.	Varietal Name	Reg. No.
Wilhelmina	279	Early Blackhull	297
Escondido	280	Superhard	298
Oregon Zimmerman	281	Cooperatorka	299
Currawa	282	Eagle Chief	300
Redhart	283	Nebraska No. 6	301
Renfrew	284	Utah Kanred	302
Arco	285	Enid	303
Golden	286	Redhull	304
Powerclub	287	Sea Island	305
Hard Federation 31	288	Whiteman	306
Axminster	289	Berkeley Rock	307
V. P. I. 112	290	Hyper	308
Montana King	291	Kruse	309
Pusa 4	292	Poso	310
Missouri Valley	293	Genro	311
Red Indian	294	Hood	312
V. P. I. 131	295	Barnatka	313
Marvel	296		

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication Dec. 9, 1935.

[2]Senior Agronomist, Wheat Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1935 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN, LOVE, H. H., and GAINES, E. F. Registration of standard wheat varieties. Jour. Amer. Soc. Agron., 18: 922–935. 1926.

The above-named wheats are here registered as standard varieties. They are commercially grown and have been described and officially recognized. However, no certificate of registration will be issued, such as are issued for improved varieties registered on the basis of performance in comparison with these and other standard varieties.

REGISTRATION OF IMPROVED WHEAT VARIETIES, IX[1]

J. ALLEN CLARK[2]

EIGHT previous reports present the registration of 48 improved varieties of wheat. In 1934, five varieties were registered, and the previous registration was referred to as in former years.[3]

Improved varieties approved for registration in 1935 are as follows:

Varietal Name	Reg. No.
Hymar	314
Comet	315
Clarkan	316

HYMAR, REG. NO. 314

Hymar (Wash. 2876, C. I. No. 11605) was developed in cooperative experiments of the Washington Agricultural Experiment Station at Pullman, Wash., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. It is the result of a cross between Hybrid 128 and Martin made by E. F. Gaines in 1923. It is a winter-habit, soft white-kerneled club wheat, very similar to Albit in appearance. It is a high-yielding variety and, according to Gaines, is expected to replace Albit in the Palouse section of Washington. About 1,000 bushels of seed were distributed for commercial growing in the fall of 1935. The advantages of Hymar over Albit are that it shatters less and has a heavier test weight per bushel and a higher average yield. It is similar to Albit in smut resistance. The comparative yield data upon which registration is based are shown in Table 1.

COMET, REG. NO. 315

Comet (N. No. 649, C. I. No 11465) was developed in cooperative experiments of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Montana Agricultural Experiment Station from a cross between Marquis and Hard Federation made in 1921. The cross and selection numbers of Comet were 21202B–1–24–50–5. Large numbers of F_2 plants were grown at Bozeman and Moccasin, Mont., in 1923 and extensive F_3 populations at Bozeman, Moccasin, and Havre in 1924. The results of the F_2 and F_3 studies were published[4]. The B–1–24 F_2 plant was the highest in crude protein content of 567 in that generation grown at Bozeman.

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 9, 1935.

[2]Senior Agronomist, Wheat Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1935 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, VIII. Jour. Amer. Soc. Agron., 27: 71–75. 1935

[4]CLARK, J. ALLEN, and HOOKER, JOHN R. Segregation and correlated inheritance in Marquis and Hard Federation crosses, with factors for yield and quality of spring wheat in Montana. U. S. Dept. Agr. Bul. 1403. 1926

TABLE 1.—*Comparative yields of Hymar and Albit winter wheats grown in nursery and plat experiments at Pullman, Walla Walla, and Pomeroy, Wash., 1931–35.*

Station and variety	Yield in bushels per acre						Percentage of Albit
	1931	1932	1933	1934	1935	Average	
			Nursery Experiments				
Pullman							
Hymar (new).....	24.9	46.8	44.5	52.7	76.5	49.1	102.3
Albit............	23.0	43.1	39.3	53.8	81.0	48.0	100.0
Walla Walla							
Hymar..........	54.5	37.0	43.7	29.5	45.5	42.0	107.1
Albit............	45.5	36.0	49.2	20.8	44.3	39.2	100.0
Pomeroy							
Hymar..........	—	29.5	0.0*	37.0	54.0	30.1	103.8
Albit..........	—	30.8	0.0*	32.0	53.2	29.0	100.0
			Plat Experiments				
Pullman							
Hymar.......	—	—	46.9	47.9	47.7	47.5	109.4
Albit	—	—	45.0	40.5	43.0	43.4	100.0

*Winter killed.

From the extensive protein studies continued on many selections up to the F_6 generation it was evident that no high-yielding strains from this cross had as high a protein content as Marquis. The selection resulting in Comet first entered the nursery yield experiments at Moccasin in 1926 and the plat experiments at Havre in 1929. M. A. Bell, of the Northern Montana Branch Station, applied for registration. He and the writer were the principal breeders and jointly named[5] the variety.

Comet is a hard red spring variety with strongly awnleted spikes, white glabrous glumes, and light-red kernels. Its superior characters are drought resistance, early maturity, and high yield. Comet is being used with excellent results as a parent in further hybrid combinations. It has not been distributed for commercial growing. The yield data upon which registration is based are given in Table 2.

CLARKAN, REG. NO 316

Clarkan (Kans. No. 505, C. I. No. 8858) was developed by Earle G. Clark, Sedgwick, Kans., from a natural Blackhull—soft wheat cross in 1916. The soft red winter wheat parent was probably Harvest Queen. The Clarkan variety was developed from a single kernel planted in 1920 and was first known as Clark's No. 40. The variety was tested by the Kansas Agricultural Experiment Station and was first distributed by Mr. Clark in 1934 after it was recommended by

[5]CLARK, J. A., and BELL, M. A. Comet wheat. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumbered Pub.] [1934] 2 pp. [Mimeographed.]

TABLE 2.—*Comparative yields of Comet and four commercial spring wheats grown in plat experiments at Havre, Moccasin, and Bozeman, Mont., 1930–35.*

Variety	Yield in bushels per acre							Percentage of Marquis
	1930	1931	1932	1933	1934	1935	Average	
				Havre				
Comet (new)	11.1	7.5	38.6	20.6	—*	13.6	18.3	118.8
Supreme	9.7	7.0	37.0	18.6	—*	12.2	16.9	109.7
Ceres	9.2	6.4	33.1	18.8	—*	10.8	15.7	101.9
Marquis	8.9	8.1	30.0	19.4	—*	10.6	15.4	100.0
Reward	9.5	5.0	32.8	12.9	—*	11.4	14.3	92.9
				Moccasin				
Comet	13.6	12.2	28.6	16.3	18.2	15.5	17.4	125.2
Supreme	12.3	10.0	23.6	14.1	16.9	14.6	15.3	110.1
Ceres	12.0	9.8	24.2	14.1	14.7	14.2	14.8	106.5
Reward	11.8	11.0	23.5	13.6	13.9	11.9	14.3	102.9
Marquis	13.6	9.7	22.3	12.3	13.2	12.0	13.9	100.0
				Bozeman				
Comet	72.2	69.1	—*	71.6	61.3	77.8	70.4	112.5
Supreme	71.5	67.7	—*	68.3	63.9	80.0	70.3	112.3
Ceres	59.6	62.4	—*	69.2	58.5	70.9	64.1	102.4
Marquis	69.3	58.7	—*	60.3	54.0	70.9	62.6	100.0
Reward	54.2	48.7	—*	48.1	56.9	62.8	54.1	86.4

*Varieties badly damaged by hail, therefore data not used.

the Kansas Station and crop improvement association to replace Harvest Queen. The advantages of Clarkan over Harvest Queen are stiffer straw and higher yield. The yield data upon which registration is based are given in Table 3. Dr. J. H. Parker of the Kansas Agricultural Experiment Station applied for the registration of Clarkan, a variety developed by a private breeder.

TABLE 3.—*Comparative yields of Clarkan and other soft red winter wheats grown in nursery and plat experiments at Manhattan, Kans., 1929–35.*

Station and variety	Yield in bushels per acre								Percentage of Harvest Queen
	1929	1930	1931	1932	1933	1934	1935	Average	
				Nursery Experiments					
Manhattan									
Clarkan	31.4	46.6	50.8	71.9	23.3	30.9	31.7	40.9	125.5
Fulcaster	26.6	45.0	38.7	60.3	18.3	26.3	30.4	35.1	107.7
Harvest Queen	21.9	36.5	42.0	56.0	18.9	26.0	27.1	32.6	100.0
				Plat Experiments					
Clarkan	—	—	51.7	49.9	45.8	33.9	25.9	41.5	122.4
Fulcaster	—	—	50.0	48.1	44.5	31.6	26.5	40.1	118.3
Harvest Queen	—	—	43.6	40.4	37.1	25.9	22.7	33.9	100.0

COTTON VARIETIES RECOGNIZED AS STANDARD COMMERCIAL VARIETIES[1]

H. B. Brown[2]

BELOW are brief descriptions of cotton varieties recognized by the American Society of Agronomy and the Agronomists of the Association of Southern Agricultural Workers as standard commercial varieties.

ACALA-5

Acala-5 belongs to the intermediate[3] group of cotton varieties. It was developed by C N. Nunn of Porter, Okla., who made plant selections in a field of Acala cotton at Okema, Okla., in 1914. The variety was developed from native stock introduced from southern Mexico in 1906 by Collins and Doyle of the U. S. Dept. of Agriculture, and grown at Waco, Texas, until 1914.

Acala-5 was grown by the originator until his death in 1934. It showed a wide range of adaptability throughout the western part of the Cotton Belt, producing well on both bottom lands and upland soils.

The plants attain a height of 2 to 5 feet, depending on the supply of moisture and soil fertility; have a strong central axis and rather slender fruit branches with rather short internodes; leaves medium sized, slightly cupped; bolls 65 to 75 per

[1]These varieties were selected by a vote of 20 cotton breeders and cotton agronomists scattered throughout the cotton-growing states. The Committee was named by the Association of Southern Agricultural Workers and worked in cooperation with the Varietal Standardization Committee of the American Society of Agronomy. The Cotton Belt was divided into five districts: Western, Texas-Oklahoma, Mississippi Valley, Mississippi-Tennessee-Alabama Hill Land District, and the Georgia-Carolina District. A local committee was designated for each district, the members of which were asked to name all the varieties of the district which they considered eligible to be listed as a standard variety. Varieties thus nominated were voted on by each local committee. Varieties receiving a majority vote by the local committee were passed on to a general committee, consisting of one member from each of the districts mentioned above, and again voted on. As a result of this procedure the varieties listed were chosen. No variety was recognized unless it represented a fairly distinct type, was of considerable commercial importance in at least some part of the Cotton Belt, was grown rather extensively in 1930, and is still being grown. New strains introduced since 1930 were not listed because they are eligible for registration as New Varieties of Merit if they can qualify. Many varieties were not recognized because they were considered as being identical or very nearly the same as other varieties. The members of the different district committees were as follows: Western District, C. B. Doyle; Texas-Oklahoma, D. T. Killough, L. L. Ligon, J. S. Mogford, R. V. Miller, H. C. McNamara, J. O. Ware; Mississippi Valley, Newman Hancock, Ide P. Trotter, J. O. Ware, H. A. York, H. B. Brown; Mississippi-Tennessee-Alabama, Newman Hancock, J. F. O'Kelly, H. B. Tisdale; Georgia-Carolina, R. P. Bledsoe, R. R. Childs, E. E. Hall, P. H. Kime, C. A. McLendon. Received for publication December 5, 1935.

[2]Louisiana Agricultural Experiment Station, Baton Rouge, La. Chairman of sub-committee on cotton registration of the Committee on Varietal Standardization of the American Society of Agronomy.

[3]Intermediate group of cotton varieties according to Brown's classification of varieties. Cotton, p. 44. McGraw-Hill Book Company, New York. 1927.

pound of seed cotton; staple 1 to 1/16 inches; lint per cent 33 to 37; seed medium sized, about 4,000 to a pound, with light gray fuzz of moderate density; plants not disease resistant, only medium early, and medium prolific.

ACALA-8

Acala-8 also belongs to the intermediate group of cotton varieties. It was originated by H. G. McKeever of the U. S. Dept. of Agriculture from a plant selection made in a field of Acala cotton in 1914 at Okema, Okla. The strain was later grown in Texas and in California. The parent stock from which this variety was developed orginally came from southern Mexico and had the same history as that from which Acala-5 was developed.

Acala-8 was grown by the breeder for 15 years. It showed considerable merit in that it seemed to be adapted to a rather wide range of soil and climatic conditions in the Southwest, had large storm-proof bolls, and possessed a fiber of excellent character.

Acala-8 plants attain a height of 3 to 5 feet under fair conditions; vegetative branches are few; fruiting branches medium short-jointed, causing plants to appear semi-clustered toward the top; leaves medium large, dark green; 60 to 70 bolls per pound; staple length 1 1/16 to 1 3 16 inches; per cent lint 35 to 38; seeds light gray color, medium size, about 3,500 to a pound; plants not disease resistant; earlier than most big-boll cottons, and productive in regions where adapted.

NEW BOYKIN

New Boykin belongs to the big-boll, medium-staple group of cotton varieties. This variety originated from a plant selection made in a field of Mebane by A. M. Ferguson at Sherman, Texas, in 1913 It was introduced in 1918 and has been grown continuously since by the originator. New selections have been made within the strain and roguing practiced. New Boykin is rather early and prolific for a big-boll cotton, and yields better than the average under unfavorable growing conditions.

Plants are medium sized to large, and somewhat rangy and open; vegetative branches 2 to 5, fruiting branches 8 to 15; leaves medium in size; 75 to 80 bolls per pound; staple 7/8 to 31/32 inch; lint per cent 37 to 40; seeds gray to white, medium sized; disease resistance fair to good; medium early for a big-boll cotton and rather productive, comparatively, in regions where grown.

CLEVELAND-5

Cleveland-5 belongs to the intermediate group of cotton varieties. It was developed by the cotton breeders of the Coker Pedigreed Seed Company from a plant selection made in a field of Coker Cleveland cotton at Hartsville, S. C., in 1921. It is probable that this original plant was a hybrid between Cleveland and some long-staple variety since it had a longer staple than is usual for the Clevelands and also had some other characteristics of another variety

Cleveland-5 has been grown by the breeder for 13 years, roguing and further selecting being done during this time to hold up the vari-

ety. This variety has as its special merits rather wide adaptability, a fair sized boll, and staple of good character.

Cleveland-5 has a medium sized plant, with 2 to 4 vegetative branches and medium length fruiting branches. Foliage is medium heavy; bolls 65 to 70 per pound; staple length 1 to 1 1/16 inches; lint per cent 36 to 40; seed brownish gray to light green, medium sized, about 3,600 to a pound; disease resistance, earliness, and productiveness medium.

CLEVELAND-884

Cleveland-884 belongs to the intermediate group of cotton varieties. It was developed by the cotton breeders of the Coker Pedigreed Seed Company from a single plant selection made in a field of Coker Cleveland 2a-2-45 at Hartsville, S. C., in 1923. The breeders have grown this variety for 14 years and subjected it to roguing and further selection. It is rather open and has a small leaf for a Cleveland. It is rather early and productive and has a fiber of good character.

This variety when grown under average conditions has plants that attain a height of 2½ to 3 feet. There are 1 to 4 vegetative branches and rather long fruit branches. Leaves are rather small; bolls 65 to 70 per pound; staple length 1 to 1 1/16 inches; lint per cent 36 to 38; seed small, 3,900 to 4,200 per pound, gray to light brown. Plants are rather early and productive and resistant to diseases in general, but have but slight resistance against wilt (*Fusarium vasinfectum*).

PIEDMONT CLEVELAND

Piedmont Cleveland belongs to the round-boll, short-staple group. It was originated by J. O. M. Smith from a plant selection made in a field of Cleveland Big Boll cotton at Commerce, Georgia, in 1914. This variety has been grown by the originator for 20 years and subjected to further selection and roguing. It has been earlier and more prolific than most other short-staple Clevelands but has a lower lint percentage.

Plants are medium to large, rather compact; foliage is medium to heavy; bolls 65 to 70 per pound; staple length 7/8 to 15/16 inch; lint per cent 34 to 36; seed brownish gray, medium sized; disease resistance, fair; earliness, medium; productiveness, good.

WANNAMAKER CLEVELAND

Wannamaker Cleveland belongs to the round-boll, short-staple group. It originated from an individual plant selection made in a field of Cleveland Big Boll at St. Matthews, S. C., by W. W. Wannamaker, St. Matthews, S. C., in 1908. The originator has grown the variety for 27 years and continued to do breeding work on it by further plant selection, mass selection, and roguing. This variety has a higher lint percentage than most Cleveland varieties, better picking bolls, and more disease resistance.

The plants are medium sized, with rather short fruit branches and 3 to 5 vegetative branches; leaves are medium large; bolls medium sized, 65 to 70 per pound; staple 7/8 to 15/16 inch; lint per cent 37 to 39; seeds brownish gray, medium sized; not a regular wilt-resistant variety but has considerable resistance; earliness medium; and productiveness good.

COOK-307-6

Cook-307-6 belongs to the round-boll, short-staple group. It originated from a plant selection made by B. C. Rhyne in a field of non-wilt-resistant Cook cotton near Auburn, Ala., in 1912. The breeding and care of the variety was supervised by the Alabama Experiment Station until 1922. It was then turned over to local breeders. The variety yields well, is very hardy, easy to pick, and very wilt resistant.

Plants are medium in size, with 1 to 2 basal vegetative branches, and rather large fruit limbs; foliage is medium to light, bolls medium sized, 70 to 85 per pound; staple 7/8 to 1 inch; lint per cent 35 to 38; seed medium sized, white to light green; disease resistance excellent; earliness medium; and productiveness good.

DELFOS

Delfos belongs to the small-boll, long-staple group. It originated from a plant selection made by H. B. Brown of the Mississippi Experiment Station in a field of Foster-120 cotton grown near Stoneville, Miss., in 1916. The variety was remarkably uniform for several years. Further plant selections have been made to preserve the type. The breeder has grown the variety for 19 years. It has been outstanding in earliness and prolificness and had a fairly uniform staple.

Delfos has rather small plants, under average conditions attaining a height of 2 to 3 feet, with 2 or 3 slender vegetative branches and numerous long slender fruit branches; leaves are small; bolls small, 75 to 85 per pound; staple length 1 1/8 to 1 3/16 inches; lint per cent, 31 to 34; seed medium sized, gray; very susceptible to cotton wilt; very early and very prolific in regions where adapted. It is especially suited to rich alluvial lands that are well supplied with moisture. (Missdel-2, Missdel-4, and other Missdel strains of the Delfos-6102 type are considered as belonging to the Delfos variety.)

DELTA AND PINE LAND-8

Delta and Pine Land-8 belongs to the intermediate group of varieties. It originated from a plant selection made by E. C. Ewing in a field of Delta and Pine Land-4 near Scott, Miss., in 1921 (Delta and Pine Land-4 was produced by crossing Mebane and Polk, the latter a local variety). Delta and Pine Land-8 was grown and tested by the breeder for about 10 years. More recently it has been grown and selected by the Louisiana Experiment Station as a good variety for northern Louisiana. It is especially adapted to poor hill lands because the plants are vigorous in growth, have a high lint percentage, and a fair staple length.

The plants are medium large, attaining a height of 3 to 6 feet, compact with rather short fruit branches; foliage is medium heavy; bolls medium sized, 70 to 80 per pound; staple length 1 to 1 1/16 inches; lint per cent 36 to 38; seed medium sized, gray; disease resistance fair to good; earliness fair; and productiveness fair.

DELTA AND PINE LAND-10

Delta and Pine Land-10 belongs to the intermediate group of varieties. It was produced by E. C. Ewing of Scott, Miss., by crossing

Express-122 and a non-commercial hybrid containing Express and Mebane blood. The cross was made in 1920. Individual plants were selected in the F_2 planting and subsequently in progeny rows. The variety was grown and tested by the breeder for a period of 11 years. It has proved to be productive over a large area of the Central South, and has a satisfactory staple length for a short cotton.

Delta and Pine Land-10 has medium sized plants, being more spreading than Delta and Pine Land-8, but not as tall; leaves are medium to fairly large, distinctly light green; boll size medium, 70 to 80 to a pound; staple length 1 to 1 1/16 inches; lint per cent 33 to 36; seed medium sized, brownish gray; disease resistance fair; medium early, and a good producer.

DELTATYPE WEBBER

Deltatype Webber belongs to the big-boll, long-staple group of varieties. It was developed from a plant selected in a field of Webber-82 near Hartsville, S. C., in 1915 by the cotton breeders of the Coker Pedigreed Seed Company. The variety has been subjected to further selection and roguing for a period of 19 years.

Plants are vigorous, have large bolls for a long-staple cotton, and staple of excellent character. The plants are erect, rather stocky, vigorous, 3 to 4 feet tall; 1 to 3 sharply ascending vegetative branches and numerous short fruiting branches; foliage medium heavy; bolls medium large, 60 to 65 per pound; staple length 1 3/16 to 1 3/8 inches; lint per cent 31 to 33; seed medium sized, 3,750 per pound, light gray to brown; susceptible to wilt; medium late, but productiveness good for a variety of its staple length.

DIXIE-TRIUMPH

Dixie-Triumph belongs to the medium-late, small-boll, short-staple group of varieties. A cross between Mebane Triumph and Dixie wilt-resistant cotton was made by W. W. Gilbert and Joe M. Johnson on the farm of Mr. Johnson near Monetta, S. C., in 1908. Hybrid strains of the cross were later grown on several wilt-infected soils in South Carolina, Georgia, and Alabama, and from one of these plantings Dixie-Triumph was developed. The variety was introduced commercially about 1915. L. O. Watson, an assistant to Mr. Gilbert, continued the breeding work after Mr. Gilbert was assigned other duties.

Dixie-Triumph resembles the Dixie parent in general plant form. It is a good, healthy, vigorous-growing variety and is very resistant to cotton wilt (*Fusarium vasinfectum*) under most conditions.

Plants large and spreading, attaining a height of 3 to 6 feet; branches are long; leaves medium sized; bolls medium sized, 65 to 75 per pound; staple 7/8 to 1 inch; lint per cent 33 to 35; seed medium small, tawny gray; disease resistance good; medium late but earlier than Dixie. Productive if boll weevils are controlled.

DIXIE-14

Dixie-14 belongs to the medium-late, small-boll, short-staple group of cotton varieties. It was developed from a plant selection made by S. P. Coker, Hartsville, S. C., in a field of U. S. D. A. Dixie cotton.

The original selection was made in 1920. The variety has been grown by the originator for 14 years and subjected to roguing and further selection. The special merits of the variety are its excellent wilt resistance and good production.

Under average growing conditions Dixie-14 plants attain a height of 3 feet, and are somewhat stocky; basal branches are small, fruiting branches long, producing a spreading type of plant; leaves are medium to heavy; bolls medium sized, 65 to 70 per pound; staple 31/32 to 1 1/32 inches; lint per cent 34 to 38; seed medium sized, greenish gray; disease resistance good; earliness medium; productiveness good.

EXPRESS-121

Express-121 belongs to the small-boll, long-staple group of varieties. It originated from a single plant selection made by W. E. Ayres in a field of Express-432 near Stoneville, Miss., in 1921. (The Express-432 was a selection from the original strain of Express.) Express-121 has been grown by the originator since 1921 and has been subjected to testing and further selection. Special merits of the variety are its earliness and fair degree of wilt resistance.

Plants are medium tall, open, and spreading with rather long fruit branches. The foliage is light; boll size small, 75 to 80 per pound; staple length 1 1/8 to 1 3/16 inches; lint per cent about 32.5; seed medium small, gray; disease resistance good, earliness and productiveness good.

LIGHTNING EXPRESS

Lightning Express belongs to the small-boll, long-staple group. It originated from a single plant selection made by the cotton breeders of the Coker Seed Company in a field of Express-350 grown near Hartsville, S. C., in 1922. The variety was grown by the originator for about 15 years and further plant selections made. The special merits of the variety are earliness, prolificness, and good length staple

Plants are of medium size with few vegetative branches, and medium length fruit branches; foliage is rather light; bolls small, 75 to 85; staple length 1 1/8 to 1 3/16 inches; lint per cent 32 to 34; seed small, gray; disease resistance good; very early and prolific.

HALF AND HALF

Half and Half belongs to the round-boll, short-staple group of varieties. It was developed by selection from Cook by H. H. Summerour of Duluth, Georgia The first selection was made in 1906. Selection work has been continued from that date to the present. The chief merits of the variety are its earliness, prolificness, high lint percentage, and adaptation to poor land.

Plants of Half and Half are small to medium in size, medium compact, with medium sized leaves; bolls medium sized, 65 to 70 per pound; staple 3/4 to 7/8 inch; lint per cent 40 to 45; seed small, grayish brown; early and productive but very susceptible to wilt and anthracnose diseases.

KASCH

Kasch belongs to the big-boll, medium-staple group of varieties. It was selected from Mebane Triumph at Lockhart, Texas, about 1912 by Ed Kasch of San Marcos, Texas. Individual boll and plant selections are made each year. The special merits of the variety are to be found in its large bolls, relatively high percentage of lint, good character of staple, and good production under Texas conditions.

Plants medium to large, rather stocky; normally have 2 to 4 vegetative branches and 8 to 15 fruiting branches; leaves are medium to large; bolls large, 45 to 60 per pound; staple 15/16 to 1 inch; lint per cent 38 to 41; seed medium sized, gray to white; disease resistance medium; earliness medium; productiveness medium.

LONE STAR

Long Star belongs to the big-boll, medium-staple group of varieties. It originated from a single plant selection made by D. A. Saunders in a field of Jackson cotton near Waco, Texas, in 1904. The variety has been selected for 30 years, the first 14 years by D. A. Saunders; more recently by John Gorham and Son of Waco, Texas. The special merits of the variety consist in its large, storm-proof bolls, uniform staple, and drought resistance

The plant size is medium to large, and there are commonly 2 to 4 vegetative branches, leaves are large; bolls large, 45 to 60 per pound; staple 31/32 to 1 1/32 inches; lint per cent 38 to 41; seed medium to large, light gray to white; disease resistance fair; earliness medium; productiveness good.

MEBANE

Mebane belongs to the big-boll, medium-staple group of cotton varieties It was developed by A. D. Mebane of Lockhart, Texas, by plant selection. The selection work was started in 1882, according to W P Patton, Jr , of Lockhart, Texas, the present breeder, with Boykin Storm-proof as parent material After a few years of selection, the characters of the variety became fairly well fixed. Breeding by making individual plant selections and massing strains of similar characters has been practiced. The work is still being continued.

The special merits of Mebane cotton are to be found in its large storm-proof bolls, high lint percentage, and excellent staple.

Plants of the variety are medium sized, sturdy in growth, with 2 to 4 vegetative branches; leaves are medium large to large; bolls 50 to 65 per pound; staple length 15/16 to 1 1/16 inches; lint per cent 37 to 40; seed medium sized, gray to white; disease resistance fair; earliness medium; productiveness good under Texas conditions, but rather poor, comparatively, in more humid regions.

MISSDEL

Missdel belongs to the big-boll, long-staple group of cotton varieties. It originated from a plant selection made by H. B. Brown of the Mississippi Experiment Station in a field of Foster-120 cotton grown near Stoneville, Miss., in 1916. This variety was selected in the same field as Delfos and was known as Delfos-631 for several years but was named Missdel in 1926 since it represented a distinct varietal type.

It differs from Delfos in that the main stem is more prominent, fruit branches shorter, bolls larger, and staple longer. The strain when first selected was lacking in uniformity, but it has been improved and made more uniform through further individual plant selection by the cotton breeders of the Mississippi Delta Experiment Station. Missdel has been characterized by its good production, excellent staple, good boll size, and the storm resistance of its bolls.

Plants are medium sized, attaining a height of 3 to 5 feet, with a rather prominent main stem, and numerous medium length fruit branches; leaves medium sized; bolls medium large, 68 to 78 per pound; staple length 1 5/32 to 1 3/16 inches; seed medium large, white to gray; plants susceptible to wilt but somewhat more resistant than Delfos; early and productive.

STATION MILLER

Station Miller belongs to the big-boll, medium-staple group. It originated from a single plant selection made by J. F. O'Kelly in 1926 in a field of Miller[4] cotton grown near State College, Miss. Breeding work is being continued by the originator by the use of field-selected seed, or by the use of seed from high yielding progenies. The main merits of this variety consist in its prolificness for a variety with a good-sized boll and its wilt resistance. It is earlier than the parent variety, more prolific, and has a higher lint percentage.

The plants are medium sized, with 1 to 3 vegetative branches; foliage is medium to heavy; bolls medium sized, 60 to 65 per pound; staple length about 1 inch; lint per cent 32 to 36; seed medium to large, white to gray; disease resistance good, especially wilt resistance; earliness medium; fruits slowly but produces well under favorable conditions.

MEXICAN BIG BOLL

Mexican Big Boll belongs to the big-boll, medium-staple group of varieties. It was developed from an individual plant selection made by the cotton breeders of the North Carolina Experiment Station in a field of Hope's Mexican Big Boll cotton grown near Rocky Mount, N. C., in 1917. The variety has been re-selected 8 or 10 times since that time, increase plats grown in isolation and rogued. The variety shows merit in that it has large bolls, good yields of uniform staple of good spinning quality, and disease resistance.

The plants of Mexican Big Boll are medium large, rather open, and have fairly heavy foliage. Bolls are large, 60 to 65 per pound; staple 1 to 1 1/16 inches in length; lint per cent 34 to 37; seeds medium to large, gray; disease resistance fair; earliness medium; and productiveness good.

OKLAHOMA TRIUMPH-44

Oklahoma Triumph-44 belongs to the early, small-boll, short-staple group of varieties. It originated from a plant selected in a field of Mebane cotton near Stillwater, Okla., in 1914. L. L. Lignon, cotton breeder for the Oklahoma Experiment Station, made the orig-

[4]Miller was very similar to Rowden, if not identical.

inal selection and has continued plant selection in the variety each year since 1914. The variety is outstanding in its earliness, prolificness, and good character of staple. It resembles the parent variety but little.

Plants are rather open in growth, medium sized, with 2 to 4 vegetative branches; foliage is relatively light; balls small, 70 to 90 per pound; staple length 29/32 to 1 inch; lint per cent 34 to 36; seed medium sized, gray to white; disease resistance fair; earliness excellent; productiveness good.

PIMA

Pima is an Egyptian variety that was developed in Arizona. Afifi cotton was imported from Egypt by the cotton breeders at the U. S. Field Station at Sacaton, Ariz., and selections made. The first outstanding strain obtained was designated as Yuma. An individual plant selection made in a field of Yuma at Sacaton in 1910 produced the variety Pima. The variety was tested for 5 years before it was introduced commercially. The special merits of Pima cotton are to be found in the length, strength, and fineness of its fiber, adapting it to purposes for which Egyptian cotton in general is used—fine dress goods, high grade tire fabrics, etc.

Pima plants, when grown under average conditions, attain a height of about 6 feet. They have few or no vegetative branches and many long fruiting branches. Leaves are large, glossy, nearly glabrous, and dark green; bolls small compared with Upland cotton, about 150 per pound; staple 1 9/16 to 1 11/16 inches; lint per cent about 25; seed small, about 13 grams per 100, very dark brown, partly fuzzy, fuzz greenish; susceptible to disease, especially "black arm". The variety is early for Egyptian type, but late compared with Upland. Average yield of lint per acre in Salt River Valley, Ariz., is about 270 pounds.

ROWDEN

Rowden belongs to the big-boll, medium-staple group of varieties. This variety was developed from Bohemian cotton by Rowden Brothers at Wills Point, Texas, about 1890. The chief merits of the variety are to be found in its large storm-proof bolls of fluffy, easily picked, mass of seed cotton, and hard-bodied, good quality fiber.

The plants are large, rangy for a big-boll variety, with rather profuse branching; leaves are very large and heavy; bolls large, 50 to 65 per pound; staple 15/16 to 1 1/32 inches; per cent lint 34 to 37; seed very large, fuzzy, and white; disease resistance fair; earliness medium; productiveness fair to good.

ARKANSAS ROWDEN-40

Arkansas Rowden-40 probably should be classed with the big-boll, medium-staple group of cotton varieties, but the boll is somewhat smaller than the average for the group. This variety originated from a single plant selection made by J. O. Ware, Fayetteville, Ark., in a field of Rowden Brothers' Rowden near Scott, Ark., in 1921. The strain was tested and increased by the Arkansas Experiment Station for several years and then turned over to R. L. Dortch for multiplication and seed sale. This variety has considerable vigor and yields better

than many varieties when grown under poor conditions. It has considerable wilt resistance and lighter foliage than most strains of Rowden.

Plants are rather large, with few basal limbs; foliage is medium; bolls medium sized, 55 to 70 per pound; staple length 1 to 1/16 inches; lint per cent 32 to 36; lint index 7.50 to 8.75; seed medium sized, 14 to 16 grams per 100, whitish gray; disease resistance medium to rather resistant; earliness medium; productiveness good.

TOOLE

Toole belongs to the medium-late, small-boll, short-staple group of varieties. This variety was developed from Peterkin by W. W. Toole, Augusta, Ga. The variety was introduced prior to 1907, but the exact date was not obtained by the writer. The special merits of the variety are to be found in its wilt resistance and vigor or production when grown under hard conditions of culture.

Toole has rather large plants with a tendency to semi-cluster; bolls medium, 65 to 75 per pound; staple short, 15/16 inch; lint per cent 35 to 37; seed small, fuzzy, light brownish-gray; disease resistance good; medium late but fairly productive if boll weevils are controlled.

STONEVILLE

Stoneville belongs to the intermediate group of cotton varieties. It originated from an individual plant selection made by H. B. Brown in a field of Lone Star 65[5] cotton grown on the farm of the Stoneville Pedigreed Seed Company near Stoneville, Miss., in 1923. The variety has been further selected, increased, and tested by the breeder for 12 years. The main features of merit of the variety are its earliness, prolificness, and uniformity of staple of fair length.

Plants of the variety are medium sized, medium spreading, with two or more vegetative branches if not spaced closely; foliage is medium light; bolls medium sized, 70 to 80 per pound; staple length 1 to 1 1/16 inches; lint per cent 33 to 36; seed medium small, gray; disease resistance poor; very early and productive.

TRICE

Trice belongs to the early, small-boll, short-staple group of varieties. The variety was developed from plant selections made by S. M. Bain of the Tennessee Experiment Station in a field of cotton known locally in Chester County, Tenn., as "Big-Boll Cluster". The first selection was made in 1906. The Tennessee Experiment Station has continued to grow Trice for about 20 years. Some further selections have been made The variety has been outstanding in earliness and prolificness.

Plants are rather small, 2 to 5 feet tall, rather compact, many approaching the semi-cluster type; basal limbs few; leaves light green, medium sized; bolls rather small, 74 to 84 per pound; staple fine, 7/8 to 1 inch, irregular; lint per cent 31 to 33; seed medium small, 13 to 14 grams per hundred, tawny colored; disease resistance poor; very early and prolific.

[5]Lone Star-65 was probably a natural cross between Trice and Saunders' Lone Star.

WILDS

Wilds belongs to the big-boll, long-staple group of varieties. It was produced by crossing Lightning Express, which was used as the pistillate parent, with Deltatype Webber. The cross was made in 1919 at Hartsville, S. C., by the Coker Pedigreed Seed Company. Since that date the variety has been subjected to additional selection, roguing and testing by the breeder. The special merits of the variety are to be found in its productiveness and boll size, which are excellent for a cotton of its staple length, and in its long, and excellent staple.

Plants are medium sized and somewhat stocky like the Deltatype parent; 1 to 4 vegetative branches, numerous rather short fruit branches; foliage heavy; bolls medium large, 60 to 75 per pound; staple length 1 3/16 to 1 3/8 inches; lint per cent 31 to 34; seed large, gray to light brown; not wilt resistant; earliness medium; productiveness good for an extra-staple variety.

BOOK REVIEW

WEED SEEDS

By Emil Korsmo. Oslo, Norway: Grøndahl & Sons. 175 pages, illus. 1935. $10.

THIS book is destined to aid materially in weed and seed investigations It contains a wealth of material, which represents the culminating effort of a life time devoted to a subject that in most countries has been somewhat neglected. Some idea of the scope and general utility of the book is apparent to any one interested in weeds from the following brief description of its contents.

The book contains descriptions and illustrations of 306 plant species characterized as weeds. The species included are those found commonly in East, West, Central and North Europe, and less commonly in South Europe and North America. There are 34 full-page colored plates each with illustrations of nine species. Each illustration in clear detail is a reproduction from hand-made plates and includes all or part of the inflorescence, a fruit depicting the method of dehiscence (for dehiscent fruits), natural and enlarged views of the seed, and finally transverse and longitudinal sections of the seed showing the position and relative size or thickness of the endosperm, embryo, and seed coats. The illustrations are all in natural colors although it must be recognized that the colors exhibited by many species are not the same in every geographical area. Preceding each plate is a description in Norwegian, German, and English of each species figured. The description covers the type of inflorescence, kind of fruit (silicle, achene, capsule, etc.), shape and size of the seed, color and appearance of the seed coat, and finally the distribution, common habitat, and methods of seed dissemination. The species are arranged according to what the author calls life forms, designated by symbols, e.g., annuals, winter annuals, biennials to perennials and perennials with rootstocks. Within each group the species are arranged in families. From the standpoint of the teacher or the taxonomist, the major

grouping is somewhat unsatisfactory, but the aim of the author has been to serve the agriculturist as well as the botanist, recognizing at the same time that the life history of a given species is affected by geographical distribution. The index lists alphabetically the botanical names of all the species together with their common names in 11 languages.

The book will doubtless find a place on the reference shelves of those who teach courses dealing with weeds and seeds and will also serve as a material aid to the investigator and the seed analyst. (R. H. P.)

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A TENTATIVE RECOMMENDATION OF TECHNIC FOR GRAZING EXPERIMENTS ON RANGE PASTURES IN ARID OR SEMI-ARID REGIONS[1]

Preparation of plan.—All publications dealing with the problem in hand should be examined before the working plan of the experiment is prepared in final form.

Location of grazing units.—Range grazing experiments to determine carrying capacity or the influence of seasonal grazing should be located on land representative of large areas of grazing land in the region to be served by this experiment. The large areas required for pastures in range grazing studies will probably be much more variable than would be acceptable for farm pasture experiments, but every

[1]Prepared by Dr. George Stewart, Senior Forest Ecologist, Division of Range Research, Forest Service, U. S. Dept. of Agriculture, with the assistance of M. W. Talbot and L. C. Hurtt, for the Joint Committee on Pasture Research. See this JOURNAL, Vol. 27: 1018–1019. 1935.

care should be taken to have the various range pastures or roughly comparable productivity, that is, they should be of approximately equal heterogeneity as to soils, exposure, slope, etc. The various pastures should be approximately equal in north to south exposure.

Size of grazing units.—Each unit grazed by one group of animals should be large enough to support over the experimental period, preferably 20 animals and at least 10. All treatments should be duplicated or run in a graduated series with each of five or six pastures used to obtain a point in order to determine where a break in the line might occur; when excessive variability requires division of pastures into smaller areas, all pastures should be divided in the same manner and at the same time.

Provision of drinking water and fences.—In range pastures one very important item is a proper distribution of drinking places. If this does not occur naturally water should be hauled to such localities as will avoid greatly unequal use of the forage. All experimental pastures should be securely fenced.

Rodent injury to pastures.—The nature and degree of rodent injury should be determined. Rodent-proof enclosures are a necessary part of many range grazing experiments.

Kind of livestock.—The kind of animals used and their sex should represent one of the most important phases of the livestock industry in the region. If lambs or calves are included with their mothers, each grazing unit should have an equal proportion of young and these of approximately equal age. When lamb crops or calf crops are to be used as a measure of treatments, the number of lambs or calves will vary somewhat. Mature stock alone will yield more reliable data regarding gain in flesh, or in flesh and wool in case of sheep, but if ewes and lambs, or cows and calves are usually grazed together on the ranges, such practice deserves representation in the experiment.

Reserve pastures and rotation of animals.—A given group of animals should not be rotated unless all are rotated. Under yearlong grazing additional pastures may be required to provide alternate seasonal use in order to prevent a large variable in the experiment as a result of wasting feed during one season and being short during another.

Weighing the animals.—Individual weights should be obtained at the beginning and at the end of the experimental period, and at intervals of about 4 weeks. In order to overcome variations in the weight of animals resulting from drinking water, weighings should be made soon after all animals have had ample opportunity to drink as much as they desire. Triplicate weighings on successive days are not feasible with the nervous semi-wild cattle used in range grazing experiments.

Supplemental feeding.—Supplemental feeding during the grazing test should be resorted to only in extreme emergency such as severe drought, supplemental pasturage being more satisfactory if the total available feed must be increased. When such an addition is made it should include all animals and the period should be for not less than 48 hours, and 72 or more are preferable.

Rate of grazing.—Rate of grazing should be expressed as unit-days or unit-months per acre. It may be wise in some cases to adjust the number of animals on a pasture from time to time to keep pace with

the forage growth, for example, in connection with study of seasonal use where it is desirable to obtain an equal degree of utilization in all pastures.

Measurement of feed consumed.—The amount of feed consumed should be measured as accurately as possible. This depends on volume present and on percentage utilization, both of which are derived by estimates. A series of estimates on small plots at definite mechanical intervals in the pasture should be provided. The person conducting the experiment should satisfy himself that his data are as accurate and reliable as feasible. Small estimate plots of 100 square feet or 200 square feet or other definite small area replicated at mechanical intervals in all parts of the area constitute one desirable method. In each large pasture 50 to 100 small plots are not too many to obtain representative data.

Plant population studies.—Forage inventory surveys to determine the plant population or species composition of the flora should be made at the beginning and at the end of the experiment, and at intervals of 3 to 5 years in a long-time trial. For this purpose there should be 3 to 5 or more permanent quadrats in each pasture charted annually, and in pastures where browse contributes appreciably to the feed these quadrats should be supplemented with annually charted brush plots. (For description see Pickford and Stewart "Ecology", 1935.)

Cost studies —Cost studies should be made only for widely different treatments and these definitely provided for in the plan of the experiment.

Duration of experiment.- Grazing experiments should be continued for 6 to 10 years or longer if necessary in order to obtain a fair average of favorable and unfavorable seasons. The experiment should be fortified with ordinary weather instruments, and additional ones when the nature of the problem requires them.

Publication of results. —In reporting the results of the experiment the researcher should present (1) review of publications dealing with the problem in hand, (2) the history of the grazing area, (3) the nature of the forages, (4) the season and kind of use, and (5) a statistical analysis of results wherever possible.

Precautions required to promote accuracy of results.—The accuracy of range grazing experiments would undoubtedly be increased by a determination of the total digestible nutrients obtained by the grazing animals, but until more digestion trials are conducted with range forages efforts should be made to reduce the controllable large variables such as those consequent upon the heterogeneity of large areas in respect to soil, slope, exposure, and vegetative cover, and to differences in the utilization of forage. Such variables are likely to be greater in range than in farm pasture experiments. More information is needed on methods of conducting range grazing experiments. It is not known whether all the data from small plots apply to the larger more heterogeneous range plots required by sparse vegetation, but the principles should be the same.

A WORD ABOUT ADVERTISING

BEGINNING with this issue of the JOURNAL, we take pleasure in acknowledging again a renewal of advertising contracts by that small group of advertisers who have supported the JOURNAL through good times and bad, and in addition, welcome one or two newcomers to our pages, as well as others who have used the JOURNAL occasionally in the past. This pronounced renewal of interest in the JOURNAL as an advertising medium would seem to justify a word at this time regarding our relations to our advertisers.

Generally speaking, advertising in a scientific journal with a rather limited circulation is looked upon by the advertiser largely as a gesture of good will, but we feel that the JOURNAL of the American Society of Agronomy covers a valuable potential market for every advertiser who uses its pages, and that advertising in the JOURNAL is not wholly an act of charity.

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YIELD AND COMPOSITION OF EARED AND EARLESS MAIZE PLANTS IN A SELFED LINE SEGREGATING BARREN STALKS[1]

R. J. GARBER, R. B. DUSTMAN, AND C. R. BURNHAM[2]

DURING the summer of 1934 a selfed strain isolated from Boone County White corn was observed to contain red-leaved plants. Closer examination showed that all the red-leaved plants were earless or barren. In the culture there was a total of 54 eared plants and 26 that were barren. This same strain was planted in 1935 and of the resultant plants 68 were eared and 25 were earless. These data indicate monohybrid segregation and suggest that the hereditary difference between the two types of plants involves only a single gene. This particular culture by 1934 had been selfed for 13 years. It is not known when the mutation occurred, but cultures grown from remnant seed of previous years showed it to have been segregating at least two generations earlier. With the exceptions to be discussed later, the eared and earless plants were very similar in general appearance, the differences becoming apparent after the ear shoots had appeared. On earless plants the normal concavity of the internodes is completely lacking or only slightly developed.[3] In two cases earless plants produced tillers and in both cases these tillers also bore small ears.

In 1934, Brunson and Latshaw[4] of Kansas reported on the effect of failure of pollination on composition and yield of corn plants. These authors included a review of the pertinent literature. In the Kansas

[1]Contribution from the Department of Agronomy and Genetics and the Department of Agricultural Chemistry, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director, West Virginia Agricultural Experiment Station, as Scientific Paper No. 158. Reeived for publication D ecember 21, 1935.

[2]Agronomist, Agricultural Chemist, and Assistant Geneticist, respectively.

[3]This earless character is similar to the "barren-stalk" characters studied by J D. Hofmeier, with the exception that in the present case the tassels of earless plants are similar to those of normal sibs, whereas one of the "barren stalk" eharacters had few or no side branches in the tassel. As yet the new earless character has not been tested for genetic identity with the two barren stalk characters. See Emerson, R. A., Beadle, G. W., and Fraser, A. C. A summary of linkage studies in maize. Cornell Univ., Agr. Exp. Sta. Mem. 180. 1935.

[4]BRUNSON, A. M., and LATSHAW, W. L. Effect of failure of pollination on composition of corn plants. Jour. Agr. Res., 49:45-53. 1934.

material, failure to produce well-filled ears was due to poor pollination, whereas in the material described here the earless condition was genetic, earless plants producing neither cobs nor grain. Since the earless character appeared in an inbred strain, the genetic backgrounds of normally eared and of earless plants should be similar. Such material was considered favorable for making a study of relative yields and plant composition.

YIELD

In 1934 the culture under consideration was planted in two individual row plats on different experimental areas. The plants were spaced approximately 15 inches apart along the row, and since the earless character does not appear until late in development, the two types, of course, occurred at random. Entire plants were harvested by cutting the stalk at the surface of the ground when the plants had reached the proper stage of maturity for ensiling. Leaves, stems, and ears on some of the plants were separated in paper bags. Each individual plant was placed in a muslin bag, hung in the drying house, and later weighed to determine the amount of dry[5] material. The plants harvested for chemical analysis were weighed, cut fine, and preserved in alcohol.

Each earless plant was paired with one that was normally eared. In no case was a paired eared and earless plant separated by more than a few feet along the row and in most cases the paired plants were adjacent (15 inches apart).

The average dry weights of the plants and plant parts, together with the significance of the differences determined by Student's method, are shown in Table 1. With respect to the entire plant the eared plants averaged 43.2 grams heavier than the earless ones, a difference which is undoubtedly significant (column 6). This difference is 31.1% of the average weight of the eared plants. With respect to the weights of leaves alone (including sheaths), the stems alone, or leaves and stems combined, the differences are significant and are in favor of the earless plants. These differences expressed in percentages of the weights of the corresponding parts of eared plants are, respectively, 36.3, 39.5, and 30.5. It is obvious from these data that the leaves alone or the stems alone of the earless plants were

TABLE 1.—*Average weights of entire and of certain parts of paired eared and earless plants of selfed strain of corn grown on the Agronomy Farm, 1934.*

Plant parts	No. of paired plants	Average dry weight in grams of		Difference	Odds	Difference in per cent of eared
		Eared	Earless			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Entire plant	14	138.7	95.5	43.2	9999+	31.1
Leaves and stems	14	73.2	95.5	22.3	768	30.5
Leaves, including sheaths	8	33.9	46.2	12.3	300	36.3
Stems	8	39.0	54.4	15.4	160	39.5

[5]At the time of weighing the material contained about 1 % moisture.

heavier than the corresponding parts of the plants with ears. On the other hand, the average weight of entire plants which bore ears was greater than the average weight of entire plants which did not produce ears. Apparently only part of the material which ordinarily would be stored in the ear is stored in the other parts of earless plants.

In 1935 additional data with the same selfed line were collected. The procedure throughout was similar to that followed the previous year except that no attempt was made to determine the weights of the leaves and stems separately. The data obtained are shown in Table 2.

TABLE 2.—*Average weights of entire and of certain parts of paired eared and earless plants of a selfed strain of corn grown on the Agronomy Farm in 1935.*

Plant parts	No. of paired plants	Average dry weight in grams of		Dif-ference	Odds	Difference in per cent of eared
		Eared	Earless			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Entire plant.	17	174.3	118.1	56.2	9999+	32.2
Leaves and stems	17	80.8	118.1	37.3	9999+	46.2

As in the previous year, the average weight of entire eared plants was significantly greater than that of earless plants, the difference being 32.2% of the former. With respect to the average weight of leaves and stems combined, the earless plants were heavier, the difference being 46.2% of the weight of the eared plants. In general, the relative yields obtained in 1935 were similar to those obtained in 1934.

In another culture, in the first generation of selfing, earless plants were found to be segregating. Weights on six pairs were determined. All differences were similar in direction to those for the other earless character. There was more variation, however, which resulted in odds which are barely significant.

COMPOSITION

At the time of harvest the most striking apparent difference between the two types of plants other than the presence or absence of ears was the coloring in the leaves. The earless plants showed an abundance of red coloring in the leaves and leaf sheaths, whereas the eared plants showed very little or none. The difference in the appearance of the leaves after extraction of most of the chlorophyll followed by treatment with iodine solution is shown in Fig. 1. The treatment removed some red pigment along with the chlorophyll. The two leaves at the left are from eared plants and the two at the right are from earless plants.

In all, eight plants were subjected to a chemical analysis similar to that ordinarily used for determining certain constituents of feed.[6]

[6]Methods of Analysis of Association of Official Agricultural Chemists Ed. 2. 1925.

Two plants or the specified parts of two plants were used to make up a sample for each analysis reported in Table 3.

The data in columns 2 and 3 show that the eared plants contained somewhat more free water and were heavier than the earless plants. On the other hand, the leaves alone of the earless plants were about

FIG. 1.—Corn leaves treated with iodine solution after extraction of the chlorophyll from eared (left) and earless (right) plants occurring in the same selfed strain grown on the Agronomy Farm in 1934. The dark streaks indicate the presence of starch, while the dark solid color indicates the presence of pigmentation.

20% heavier than the leaves of the eared plants. Apparently the earless plants were slightly the more mature at the time of harvest. The relative weights of the two types of plants have been discussed above in connection with more adequate data and need not be repeated here, other than to point out again that the total weight of the eared plants is considerably greater than the total weight of the earless plants.

Comparing the percentage compositions (columns 4, 5, 6, 7, and 8, Table 3) of entire plants, it is found that the earless plants analyzed higher in ash, crude protein, and crude fiber and lower in ether extract and nitrogen-free extract. With respect to the leaves alone,

TABLE 3.—*Weights and various constituents of eared and earless plants of a selfed strain of corn grown on the Agronomy Farm in 1934.*

Sample*	Percentage H_2O at harvest	Dry matter, grams	Percentage composition on dry matter basis				
			Ash	Crude protein	Ether extract	Crude fiber	N-free extract
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
I, entire plant, *earless*	66.50	183.1	5.08	12.76	2.39	18.74	61.00
II, entire plant, *eared*	67.16	230.7	4.15	9.95	3.51	17.05	65.32
III, leaves, *earless*†	69.28	78.8	6.23	13.04	3.67	18.71	58.35
IV, leaves, *eared*	70.91	65.3	6.68	13.17	4.84	22.81	52.47
V, stems, *earless*	67.79	91.0	3.04	10.80	1.13	18.28	66.73
VI, stems and ears, *eared*	69.93	205.2	2.55	7.89	2.05	18.25	69.23

*Each sample from two plants.
†Samples III and V from same plants; likewise samples IV and VI from same plants.

the earless plants were slightly lower in percentage of ash and of crude protein, distinctly so in ether extract and crude fiber, and markedly higher in percentage of nitrogen-free extract. The stems and ears together from the eared plants ran lower in ash and crude protein but higher in ether extract and nitrogen-free extract than did the stems of the earless plants. Practically no difference was found in the percentage of crude fiber. These analyses show that certain differences in percentage compositions of ash, crude protein, ether extract, crude fiber, and nitrogen-free extract existed between eared and earless plants at the time of harvest.

Certain carbohydrate fractions of the two types of plants were determined by the official methods, using samples of the same material previously reported. The percentages of the several constituents are shown in Table 4, columns 2, 3, 4, 5, and 6. The analyses of

TABLE 4.—*Carbohydrate constituents of eared and earless plants of a selfed strain of corn grown on the Agronomy Farm in 1934.*

Sample*	Percentage composition on dry matter basis				
	Total sugar (as invert sugar)	Reducing sugar (as glucose)	Starch (0.9 x glucose value)	Hemicellulose (as glucose) (1% HCl)	Total carbohydrate
(1)	(2)	(3)	(4)	(5)	(6)
I, entire plant, *earless*	26.64	7.93	3.36	11.41	41.41
II, entire plant, *eared*	17.91	4.19	14.21	13.81	45.93
III, leaves, *earless*†	18.12	5.61	1.93	12.71	32.76
IV, leaves, *eared*	13.39	4.99	2.66	11.61	27.66
V, stems, *earless*	35.36	32.84	3.88	7.52	46.76
VI, stems and ears, *eared*	25.08	17.78	12.02	10.29	47.39

*Each sample from two plants.
†Samples III and V from same plants; likewise samples IV and VI from same plants.

entire plants showed that the earless individuals contained distinctly more total sugar and reducing sugar and distinctly less starch than was contained in the eared individuals. With respect to the hemicellulose fraction and total carbohydrates, there was relatively less difference, but the difference that was found was in favor of the eared plants. The analyses of the leaves alone for total sugar, reducing sugar, and starch showed differences similar to but somewhat less marked than those for the entire plants. The leaves from earless plants showed a considerably higher percentage content of total carbohydrate and a slightly higher content of the hemicellulose fraction than did the leaves from the eared plants. The analyses of the stems of the earless plants and the stems and ears together of the eared plants showed relative differences similar to those from the analyses of entire plants. The total carbohydrate difference of the latter was somewhat more marked than of the former where the leaves were not included.

DISCUSSION

The data reported in this paper are somewhat similar to those reported earlier by Brunson and Latshaw. These authors showed the relative effect of no pollination and incomplete pollination on yield and composition of the corn plant, whereas in the present paper is discussed the influence of a monohybrid character, "earless", on composition and yield within the same selfed line.

The leaves alone or the stems alone of the earless plants weighed more than the corresponding parts of normally eared plants. On the other hand, the total weight of entire eared plants was markedly greater than entire earless plants.

The leaves of the earless plants were not only heavier than the leaves of the eared plants, but they contained a greater percentage composition of nitrogen-free extract and a lesser percentage of crude fiber, thus indicating their superior feeding value. A separate analysis of the stems alone of each class of plants was not made, but it seems probable that if such analyses had been made differences similar to those found in the leaves would have been obtained. The percentages of ether extract in the eared plants were consistently greater in all analyses than in the earless plants, although the differences were not very great (approximately 1%).

Both the chemical analyses and the relative yields indicate that the feeding value per acre of the earless plants is greater than that of the eared plants without the ears. On the other hand, the feeding value per acre of entire eared plants is markedly greater than that of entire earless plants.

The relative feeding value and yields of the two types of plants in this material is of less interest than the distribution of the several carbohydrates studied (Table 4). The entire earless plants were much richer in total sugar and reducing sugar than were the eared plants. Conversely, the latter contained much more starch, evidently stored in the ear, than was contained in the former. In this connection it is interesting to note that somewhat less starch was found in the leaves of the earless plants than in those of the eared plants. This outcome differs from the results of qualitative tests for starch on

other leaves from similar plants. In the latter instance the leaves from the earless plants contained more starch as judged from the iodine test after removal of the chlorophyll (Fig. 1). Apparently in this case there was no tendency to build up a high starch reserve in the leaves of either type of plant. Likewise, the starch content of the stems only from the two earless plants compared with that of the stems and ears together of the two eared plants suggests that the starch reserve in the stems was relatively low in both types of plants. The total sugar was considerably higher in the leaves and in the stems, and the reducing sugar as glucose was much higher in the stems from the earless plants than from the corresponding parts of the eared plants. The earless condition apparently did not interfere with the normal photosynthetic and metabolic processes in the leaves, but owing to the fact that the usual storage organ (the ear) was not present there resulted an accumulation of sugars in the leaves and stems greater than ordinarily occurs. This accumulation was also reflected in the coloring which developed in the earless plants. Similar excess coloring develops in the leaves of normal plants when translocation is interfered with by injury.

The earless plant discussed in this paper is a good example of the profound influence of what apparently is a single gene. The complete absence of an ear is in itself a striking abnormality, but when one considers the whole chain of reactions which may result from this abnormality, the influence of this single gene becomes more striking. The statement has been made that the influence of a particular gene may be determined quite as much by the genotypic complex in which it is functioning as by the gene itself. Here we have an instance of two types of plants which presumably have essentially the same genotypic matrix, except for a single gene, but this single gene both directly and indirectly has a marked influence on growth and development.

SUMMARY

A study was made of the weights and composition of plants and plant parts of normally eared and earless individuals in the same selfed strain of corn. "Earless" behaved as a monohybrid recessive. The stems and leaves of the earless plants weighed more and contained a higher percentage of sugars than did the stems and leaves of the eared plants. With respect to entire plants, the eared individuals weighed significantly more and contained a higher percentage of total carbohydrates and of ether extract than the earless individuals. The percentage of crude protein was somewhat greater in the earless plants.

CHARACTERISTICS OF SOME MORPHOLOGICAL SOLONETZ SOILS OF MINNESOTA[1]

Clayton O. Rost[2]

THE occurrence of soils with solonetz morphology in the United States and Canada has been reported by a number of investigators. Carpenter and Storie (2)[3] called attention in 1928 to the presence of such soils in California and reported the mechanical analysis, moisture equivalents, and reactions for representative samples. In 1930 Nikiforoff (10) dealt with the morphology of the profile of this genetic class of soils and described characteristic profiles found in the Minnesota portion of the Red River Valley. Since then, Kelley (5) has studied profiles of such soils occurring in California and Kellogg (7) has dealt with those occurring in western North Dakota. In connection with a study of clay-pan soils, Brown, Rice, and Byers (1) have analyzed a morphological solodized solonetz from Wilkin County, Minnesota, and a member of the Phillips series from northern Montana which probably belongs to the same genetic class. Recently, Murphy and Daniel (8) have contrasted solonetz and normal soils in relation to their erodibility and Ellis and Caldwell (3) have called attention to the occurrence of morphological solonetz soils in Manitoba which have failed to show appreciable quantities of adsorbed Na.

The present study reports some of the physical and chemical characteristics of samples of soil from six representative profiles with solonetz morphology from Wilkin and Traverse counties, Minnesota.

OCCURRENCE OF MORPHOLOGICAL SOLONETZ IN MINNESOTA

Soils with morphological characteristics of solodized solonetz occur in spots of variable size in parts of the Red River Valley in Minnesota but appear to be more common in the southern part. The individual spots are relatively small and make up in the aggregate only a small portion of the total area. They range in size from a rod or less to 4 or 5 rods in diameter and may occur as isolated spots or be relatively numerous in a given area. In one area in Nordick Township, Wilkin County, the spots were so numerous over the distance of three-quarters of a mile as to give the impression of an almost continuous exposure of this kind of soil. The spots appear to lie on the slopes of very slight depressions, but such depressions are usually so slight as to be scarcely visible to the eye.

These soils are associated with the fine-textured members of the Fargo series which occupy the central part of the valley near the Red River where the natural drainage is best developed. It seems prob-

[1]Contribution from the Division of Soils, University of Minnesota and published with the approval of the Director of the Minnesota Agricultural Experiment Station as Paper No. 1394 of the Journal Series. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 12, 1935.

[2]Professor of Soils. The author is indebted to Caroline Chamberlain, Jean Zetterberg, and K. A. Maehl for assistance with chemical analyses.

[3]Figures in parenthesis refer to "Literature Cited", p. 104.

able that following the escape of the main body of water from glacial Lake Agassiz numerous shallow lakes and swampy areas remained and before drainage developed much of this water escaped through evaporation. This partly accounts for the salinization of many of the soils (10). As the natural drainage gradually improved the areas nearest the river where the finest sediments were deposited were affected first and there desalinization has proceeded more rapidly than in the areas nearer the valley edge.

The mean annual precipitation of the area in which profiles were studied is 22.3 inches (56.6 cm) and of this 18.6 inches (47.5 cm) falls during the seven-month period of April to November.

MORPHOLOGY OF THE PROFILE

The characteristic profile of solodized solonetz as displayed in Minnesota has already been described by Nikiforoff (10). The A_1 horizon ranges in thickness from 2 to 8 inches, is black to dark gray in color, and has a poorly developed granular or more frequently a lamellar structure. The boundary between it and the underlying A_2 is irregular. The latter horizon is light gray to ashy gray in color and varies in thickness from a fraction of an inch to as much as 10 inches. It has a finely lamellated, vesicular structure with the upper sides of the plates lighter in color than the lower. Within the same spot the thickness of the A_1 and A_2 horizons may be quite variable.

Between the A_2 and the B horizons the line of demarcation is very sharp. The thickness of the latter varies from 5 to 15 inches, the soil is black, very compact, sticky when wet, and very hard when dry. It has a well-developed columnar structure in the upper part, the columns varying in length from 2 to 5 inches and in width from less than an inch to more than 2 inches. Below them the soil is massive and fractures into rather large irregular lumps.

The C horizon is gray to very dark or olive gray, a silty clay or clay and compact and sticky when wet. The A and B horizons rarely show any effervescence but the C horizon is highly calcareous. Usually the A_1 and A_2 horizons are practically free of soluble salts, but these occur in B and C horizons in varying amounts.

PROFILES STUDIED

Of the six profiles sampled for this study, five (Nos. 1 to 5) were in Wilkin County and one (No. 6) in Traverse County. All profiles displayed morphological characteristics of solodized solonetz and may properly be described as such, although the A_2 horizon of profile 5 consisted of only a thin line of light-colored powder resting on the caps of the columns of the B_1 horizon and was so thin that it could not be sampled.

Where profiles could be sampled in 4-inch layers this procedure was followed but in no case was there a portion of two horizons included in one sample. Since the transition from the B to C horizon is gradual this is ordinarily included in one 4-inch sample and in the present study has been designated the BC transition zone. In all cases the samples represent continuous profiles through the B horizon and in four cases the upper portion of the C horizon as well.

The thicknesses of the different horizons in the six profiles are shown in Table 1. Profile No. 2 was located in the same area of solonetz from which the samples used by Brown, Rice, and Byers (1) were taken, so that their data will be applicable to this case at least.

TABLE 1.—*Horizon thickness of profiles with solodized solonetz morphology.*

Horizon	Inches of profile number						Average, inches
	1	2	3	4	5	6	
A_1........	6	5	4	8*	6	8*	6
A_2........	6	5	4	4	0	4	4
B.........	8*	12†	8*	12†	13†	8*	10
BC.......	4	4	4	—	4	4	4
C‡........	8	4	10	—	—	12	8

*Sampled in two sections
†Sampled in three sections.
‡Portion sampled.

METHODS USED

Soluble Salts.—Fifty grams of soil were extracted with CO_2-free distilled water until the leachate was free of sulfates, since preliminary tests had indicated that the alkali salts were mainly sulfates and that gypsum was present in most of the samples. The leachate was evaporated to dryness, the residue carefully ignited to free it of organic matter, cooled, and weighed. It was then extracted with 25 ml. of hot water, filtered rapidly, and washed several times with a few ml. of hot water. The filtrate was evaporated to dryness and the residue dried and weighed. The difference between the two weighings was assumed to represent the $CaSO_4$ present and the last weight the amount of soluble salts or "alkali" salts The soluble salts were dissolved in distilled water, made up to 250 ml., and the chlorides, bicarbonates, and magnesium determined by the ordinary methods. Since chlorides were absent the magnesium was calculated to $MgSO_4$, the carbonate and bicarbonate to Na_2CO_3, and the difference between the sum of these and the total soluble salts was calculated as Na_2SO_4.

Reaction.—The hydrogen-ion concentration was determined electrometrically, using a bubbling hydrogen electrode.

Texture.—The texture is expressed as the moisture equivalent.

Replaceable bases.—Twenty-five-gram samples of soil were leached with distilled water to the disappearance of sulfates and then with alcoholic (68%) barium chloride, according to the method of Magistad and Burgess (9), until calcium was no longer present in the leachate. The excess barium was precipitated with Na_2CrO_4, filtered off, and the amounts of Ca, Mg, Na, and K in the filtrate determined by standard methods.

RESULTS

SOLUBLE SALTS

In the present study the salts soluble in water have been divided into two groups, *viz.*, (a) calcium sulfate which is not considered as being an alkali, and (b) the alkali salts consisting of the sulfates of magnesium and sodium and carbonates and bicarbonates of sodium. Under the method employed bicarbonates were converted to car-

bonates and determined as such. Ellis and Caldwell (3) have very recently pointed out that the solonetz soils of Manitoba are devoid of sodium carbonate, but that the bicarbonate is one of the dominant ions. In the present study this item was not investigated.

Calcium sulfate (Table 2) is present in all horizons of five profiles but in relatively small amounts until the BC transition zone or C horizon is reached when the amounts increase sharply. The largest amounts are found in the C horizon where nests of gypsum crystals were frequently encountered. The surface layer of soil carried slightly more than the second layer indicating some accumulation at or on the surface due to evaporation. The A_1, A_2, and upper part of the B horizons of profile 2 are essentially free of $CaSO_4$, although in the lower part of the profile it is present in larger quantities than in the other profiles. Above the BC transition the largest amount present in any profile is 515 p.p.m. in the second 4-inch layer of the B horizon of profile 1, while the largest amount present in the C horizon is 2,547 p.p.m. in profile 2.

TABLE 2.—*Amounts of $CaSO_4$ in profiles with solodized solonetz morphology.*

Horizon	p.p.m. of $CaSO_4$ in profile number						Average, p.p.m.
	1	2	3	4	5	6	
A_1	295	T	210	165	207	82	160
A_2	25	T	57	97	—*	85	53
B†	328	T	125	240	129	42	144
	515	185	125	240	127	[illegible]2	217
	—	175	—	275	335	—	262
BC	357	880	1,030	—	1,025	945	845
C	1,763	2,547	1,200	—	—	2,285	1,949

*Horizon too thin to sample.
†Sampled in 4-inch sections.

The A_1 and A_2 horizons are either free of alkali salts or carry them in only very small amounts (Table 3). In three profiles, Nos. 2, 5, and 6, the upper part of the B horizon is almost free of such salts, but in the remaining three the total salt content increases from the top of the B horizon into the C where it reaches a maximum. The total amounts are variable from profile to profile. Profile 1 carries the largest amount and profile 2 the least, the range in the former being between 1,835 p.p.m. in the upper part of the B and 7,034 p.p.m. in the C horizon, while in the latter it is between 107 p.p.m. in the B horizon (17- to 20-inch layer) and 1,367 p.p.m. in the C.

When the entire profile is considered the soluble salts consist chiefly of $MgSO_4$, while Na_2CO_3 or $NaHCO_3$ are present in smaller amounts and chlorides are absent entirely. The $MgSO_4$ exceeds the Na_2SO_4 in profiles 1, 2, 3, and 6, but for the remaining two the reverse is true.

TEXTURE

In texture the soils of the six profiles vary from silt loams to clays. The moisture equivalents (Table 4) show profile 5 to have the finest texture when the entire profile is considered, the range being between

TABLE 3.—*Alkali salts in profiles with solodized solonetz morphology.*

Horizon	p.p.m. of salts in profile number 1	2	3	4	5	6	Average, p.p.m.
			Total Salts				
A_1	122	0	162	35	129	142	99
A_2	125	0	198	90	—*	35	90
B	1,835	0	855	945	204	200	673
	5,250	107	755	3,040	132	490	1,629
	—	277	—	3,240	280	—	—
BC	5,420	892	1,905	—	3,880	1,829	2,785
C	7,034	1,367	2,075	—	—	2,740	3,304
			$MgSO_4$				
B†	1,015	0	170	176	—	—	—
	2,596	—	127	1,286	—	35	—
	—	62	—	1,392	20	—	—
BC	2,620	550	1,120	—	1,459	921	1,334
C	4,445	1,035	1,493	—	—	1,900	2,218
			Na_2SO_4				
B	555	0	413	662	—	—	—
	2,322	—	371	1,641	—	322	—
	—	52	—	1,723	68	—	—
BC	2,515	181	572	—	1,833	726	1,165
C	2,375	164	392	—	—	571	876
			Na_2CO_3 and $NaHCO_3$				
B	265	0	272	107	—	—	—
	332	—	257	140	—	133	—
	—	163	—	125	192	—	—
BC	285	161	213	—	88	182	186
C	214	168	190	—	—	269	210

*Horizon too thin to sample.
†Only total salts determined for the A horizon

40.0 and 45.7. The values are lowest for profile 6 where they vary between 15.9 for the A_2 horizon and 31.7 for the upper part of the B. There is the same general variation between horizons and subhorizons within all profiles. The moisture equivalent of the A_2 is markedly lower than that of the A_1 with a sharp rise in the upper part of the

TABLE 4.—*Moisture equivalents of profiles with solodized solonetz morphology.*

Horizon	Profile number 1	2	3	4	5	6	Average
A_1	23.7	38.1	32.5	32.8	40.2	27.3	32.4
A_2	19.5	24.7	23.3	18.3	—*	15.9	20.3
B	35.9	39.4	30.7	37.0	44.6	31.7	36.5
	35.3	38.2	29.1	36.3	45.7	30.1	35.8
	—	38.3	—	33.2	42.1	—	—
BC	31.8	33.9	30.5	—	40.0	29.2	33.1
C	32.2	33.9	34.4	—	—	30.6	32.8

*Horizon too thin to sample.

B where ordinarily it reaches a maximum for the profile. There is a slight decrease in the lower part of the B followed by further slight decreases in the BC and C horizons. Profile 3 is the only one to present an exception and in this the moisture equivalent for the C is slightly higher than for the B horizon.

The mechanical analysis of samples taken from a profile located in the same spot of solodized solonetz as profile 2 and reported by Brown, Rice, and Byers (1) shows the A_1 and A_2 horizons to be much richer in sands and silt and much poorer in clay than the B horizon, while the latter does not differ much in mechanical composition from the underlying C horizon. The percentages of sands and silt were slightly higher in the A_2 than in the A_1, but the former carried a correspondingly lower percentage of clay. Colloids were highest in the B horizon where they were 58.8% as compared to 53.9% in the C. The lowest percentage, 19.5, was found in the A_2, while for the A_1 it was 27.9%. These data and the moisture equivalents as determined in the present study are in agreement and indicate a marked disintegration of the complex of the A horizon and some eluviation of colloid into the B horizon. The moisture equivalents would indicate eluviation of colloids into the B horizons of profiles 1, 2, 4, and 5 but little, if any, in profiles 3 and 6.

REACTION

The hydrogen-ion concentration of the soil from the six profiles (Table 5) decreases with depth. In all cases the A_1 is acid and wherever this horizon was sampled in two layers (profiles 4 and 6) the lower part was more acid than the upper. The pH values for the former were 6.2 and 5.6 and for the latter 6.6 and 6.1, respectively, for the upper and lower parts. The most acid A_1 horizon is that of profile 1 which has a pH of 5.7 and the least acid are those of profiles 2 and 3 which are pH 6.4. In the majority of cases the reaction of the A_2 horizon is similar to that of the A_1. An exception to this is found in profile 2 where the A_2 horizon showed a pH of 7.6 as compared to 6.4 for the A_1. These figures are in agreement with those reported by Brown, Rice, and Byers (1) who found pH values of 6.3 and 7.5, respectively, for the A_1 and A_2 horizons. The reaction of the soil in the B horizon is usually above pH 7.0, although in the case of profile

TABLE 5.—*Reaction of profiles with solodized solonetz morphology.*

Horizon	pH of profile number						Average, pH*
	1	2	3	4	5	6	
A_1	5.7	6.4	6.4	5.8	5.8	6.3	6.0
A_2	5.9	7.6	6.3	6.2	—†	6.5	6.2
B	7.0	8.2	7.8	6.8	6.9	7.6	7.1
	7.4	8.4	8.1	7.5	7.6	8.2	7.7
	—	8.0	—	7.9	8.1	—	—
BC	8.1	7.7	7.9	—	7.8	8.3	8.0
C	8.1	7.8	8.3	—	—	7.9	8.1

*Calculated from average of cH values.
†Horizon too thin to sample.

4 the upper part of the horizon is very slightly acid, the pH being 6.8. The reaction of the C horizon is in all cases close to pH 8.0 and all samples effervesce freely when tested with dilute acid.

EXCHANGEABLE BASES

Solonetz soils are usually considered to be characterized by a partially destroyed absorptive complex in the eluvial horizon and by a rather high percentage of a monovalent ion or ions, chiefly sodium, in the complex of the illuvial horizon. If it be assumed that the original parent material of the Red River Valley soils was uniform in character, the amounts of exchangeable bases (Table 6) indicate that there has been a very marked modification in the A horizon of the six profiles. The modification has been greatest in the lower part or A_2 horizon as shown by a sharp decrease in the total exchangeable bases. Since the entire horizon is acid there will be some exchangeable hydrogen which, in the present study, was not determined but which would increase the exchange capacity and decrease the percentages of the other bases. The total exchangeable bases rise very markedly in the B horizon, usually reaching a maximum for the profile in the central portion of the horizon. In the C horizon there is again a slight decrease. In respect to the partially destroyed complex in the A horizon the Minnesota profiles appear, then, to meet the solonetz requirement.

TABLE 6.—*Exchangeable bases in M. E per 100 grams of air-dry soil in profiles with solodized solonetz morphology.*

Horizon	M. E. of exchangeable bases in profile number						Average, M. E.
	1	2	3	4	5	6	
A_1	32.9	33.4	27.1	29.3	30 9	25.7	29.9
A_2	11.5	13.5	17.9	12.6	---	12.6	13.6
B	35.4	47.4	32.2	32.6	40.7	30.4	36.4
	39.3	40.9	35.3	42.1	40.1	32.1	38.3
	—	42.8	—	39.0	41.7	—	—
BC	41.2	39.0	35.6	—	43.1	32.4	38.4
C	38.8	36.7	40 2	—	—	26.1	35.1

According to Gedroiz (4), a partially destroyed eluvial horizon is evidence of an earlier stage, that of salinization with soluble salts of sodium. In the six profiles both exchangeable Na and K are present in very small amounts and, in the present stage of development, appear to be relatively unimportant (Table 7 and Fig. 1). Exchangeable Mg, on the other hand, is present in relatively large amounts and is the most prominent ion of the absorptive complex.

In the A_1 horizon the amounts of exchangeable Mg in four of the six profiles (Nos. 1, 3, 4, and 6) are not exceptionally high and the ratio of Ca to Mg is not far below that found for the upper part of the A horizon of the undegraded chernozems of the same area. The percentage of exchangeable Ca in the A_1 horizon of the four profiles varies between 66.1 (profile 6) and 71.9 (profile 3) of the total bases

TABLE 7.—*Distribution of exchangeable Ca, Mg, Na, and K in profiles with solodized solonetz morphology.*

Horizon	Percentage in profile number						Average, %
	1	2	3	4	5	6	
			Calcium				
A_1	66.9	44.6	71.9	68.5	41.1	66.1	59.9
A_2	55.7	29.6	43.0	50.8	—	60.6	47.9
B	25.1	15.2	22.4	22.7	28.8	32.9	24.5
	32.8	19.1	29.5	16.6	27.9	44.2	28.3
	—	28.5	—	19.0	30.2	—	—
BC	61.4	60.3	45.2	—	44.1	52.2	52.6
C	71.6	78.8	53.2	—	—	48.3	63.0
			Magnesium				
A_1	31.3	52.7	26.2	27.2	54.7	30.6	37.1
A_2	40.8	58.5	48.6	44.4	—	35.1	45.5
B	70.9	75.7	70.8	72.7	64.6	62.5	69.6
	65.9	79.2	65.7	78.4	68.8	53.3	68.5
	—	68.3	—	76.2	66.9	—	—
BC	36.1	38.2	52.2	—	52.7	47.2	45.3
C	26.8	20.4	45.0	—	—	48.2	35.1
			Sodium				
A_1	0.6	1.2	1.1	2.3	2.6	1.2	1.5
A_2	1.7	6.7	7.8	4.0	—	3.2	4.7
B	3.1	5.5	5.6	3.0	4.7	2.3	4.0
	1.0	1.7	4.0	4.0	3.0	1.5	2.5
	—	1.6	—	3.8	2.1	—	—
BC	1.0	0.5	0.9	—	2.1	0.6	1.0
C	0.8	0.0	0.5	—	—	0.1	0.4
			Potassium				
A_1	1.2	1.5	0.8	2.0	1.6	2.1	1.5
A_2	1.7	5.2	0.6	0.8	—	1.1	1.9
B	0.9	3.6	1.2	1.6	1.9	2.3	1.9
	0.3	—	0.8	1.0	0.3	1.0	0.7
	—	1.6	—	1.0	0.8	—	—
BC	1.5	1.0	1.7	—	1.1	—	1.1
C	0.8	0.8	1.3	—	—	3.4	1.5

determined, while for Mg the variation is between 26.2 and 31.3%. The ratio of Ca to Mg varies from 2.16 (profile 6) to 2.74 (profile 3). The percentage of exchangeable Mg in the A_1 horizon of the two remaining profiles, Nos. 2 and 5, is much higher, comprising 52.7 and 54.7, respectively, of the total bases and having Ca:Mg ratios of 0.85 and 0.75. The highest percentage for Na in the A_1 horizon is 2.6 in profile 5, while for K it is 2.1 in profile 6. The average percentages of exchangeable Ca and Mg in the A_1 horizon of the six profiles are 59.2 and 37.4, respectively, while Na and K each constitute 1.5%.

When the A_2 horizon is reached, the percentage of Ca in the complex falls perceptibly and varies between 29.6 and 60.6 of the total bases, while the percentages of Mg, Na, and K rise. The greatest increase in Mg is in profile 3 where the percentage rises from 26.2 in the A_1 to 48.6 in the A_2 horizon, and least in profile 6 where the

increase is from 30.6 to 35.1%. When the average amounts of exchangeable bases are considered, it is seen that the percentages of Ca and Mg are almost identical, *viz.*, 47.9 and 45.5. The increase in exchangeable Na and K is on the average from 1.5% for both in the A_1 to 4.7 and 1.9%, respectively, in the A_2.

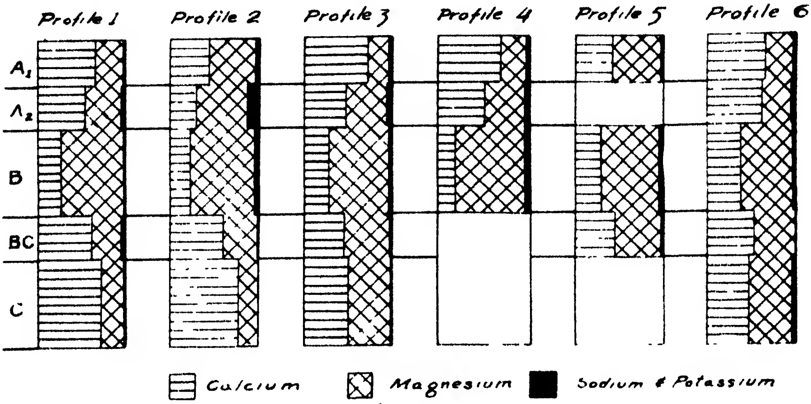

FIG. 1.—Diagram showing percentages of exchangeable bases in the different horizons of the six profiles studied.

As would be expected there is a very sharp increase in the total amount of exchangeable bases in the B horizon. The increase in the upper part of the horizon is due almost entirely to exchangeable Mg as there is a relatively small increase in the amount of exchangeable Ca, and while the amounts of Na and K in some cases are more than double those found in the A horizon, they still constitute, on the average, only 6% of the exchangeable bases. The average of total bases is 36.4 M. E. and of this Ca constitutes 24.5 and Mg 69.6%. In the lower part of the B horizon the Ca increases considerably, the Mg, Na, and K decrease somewhat and the sum of total bases rises slightly. Exchangeable Mg still constitutes from two-thirds to three-fourths of the exchangeable bases in all but profile 6 where it is slightly over half, 53.3%. The highest percentage of exchangeable Na is found in profile 3 where the average for the horizon is 4.8. Considering the amounts of exchangeable Mg and Na in the B horizon of all profiles, Na could not be considered as a dominant ion and in this respect the soils fail to meet the chemical requirement for solonetz classification. When the transition layer, BC, is reached the amount of total bases remains the same as in the lower part of the B, but there is a marked increase in exchangeable Ca and a corresponding decrease in exchangeable Mg. On the average the Ca rose to 52.6% of the total exchangeable bases, while the Mg fell to 45.3%. There was a decrease in exchangeable Na but K remained practically constant.

The sum of the total bases decreases slightly on the average when the C horizon is reached. In three of the four profiles for which samples were analyzed there was a distinct increase in exchangeable Ca. In

one (profile 6) both the amount and percentage decreased. The average for the horizon in the four profiles is 63.0%, an increase of 10% over the average for the BC transition layer, while there was a decrease of 10% in exchangeable Mg and a decrease from 1.0 to 0.4% of exchangeable Na.

It is to be noted that insofar as exchangeable bases are concerned the B horizon of profile 5, in which the A_2 horizon is only rudimentary, is very similar to that of the other horizons. The A_1 however carries a higher percentage of exchangeable Mg than profiles 1, 3, 4, and 6, but is similar to that of profile 2 where the A_2 horizon is 5 inches thick.

The chemical analysis of the soil by Brown, Rice, and Byers (1) likewise indicates a marked disintegration of the absorptive complex of the A horizon. When their data are calculated to the basis of material free of volatile matter, carbonate, and sulfate, this is very evident (Table 8). In making such calculations for the C horizon, where free carbonates of both lime and magnesium occur, their figure of 71.5% SiO_2 was used as a basis. In the others the carbonates and sulfates have been calculated as $CaCO_3$ and $CaSO_4.2H_2O$.

TABLE 8.—*Chemical analysis of Fargo sample (solodized solonetz) calculated on the basis of material free of volatile matter, carbonate, and sulfate from the data of Brown, Rice, and Byers (1).*

Horizon	Depth, in.	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	MgO %	CaO %	K_2O %	Na_2O %
A_1	0-6	80.41	2.72	10.60	1.21	0.76	1.87	1.06
A_2	7-10	82.46	3.01	8.33	0.76	0.70	2.00	1.41
B	12-20	71.41	5.63	15.78	2.55	0.32	1.98	0.81
C	32-48	71.50	5.67	17.10	----	----	2.54	0.97

It is seen that the percentage of silica is markedly higher in the A than in the B horizon, while the alumina, iron, and magnesia are lower. The soda is distinctly higher, but the potash shows little variation. The percentages of constituents in the B horizon are in the main quite similar to those in the C. This is especially true for silica, iron, and soda, but for alumina and potash the percentages are slightly higher in the C horizon. This similarity between the B and C horizons has led Brown, Rice, and Byers to conclude that the B horizon is essentially impermeable to water and that the eluviated constituents from the A horizon have been carried away by lateral erosion through the A_2 or along the top of the B horizon. From the data it is not clear as to the destination of the constituents removed from the A horizon, although there would appear to be some question as to the impermeability of the B horizon. The latter is essentially free of carbonates and if an original uniform parent material is assumed these must have been removed by percolating water. The fact that soluble salts are much lower in the B horizon than in the C would indicate some downward movement of water, although in order to maintain this condition the downward movement would only need to be great enough to exceed the upward movement. The columnar structure and vertical cleavage would also tend to facilitate the movement of water into the B horizon.

Recent studies by Russian investigators (11, 13, 14), mentioned later, indicate that magnesium in the complex has only a limited effect as a peptizer and that the filterability of soils, the complex of which has been saturated with magnesium, resembles more nearly those saturated with calcium than those saturated with sodium. In the present study it was observed that in the filtering operation for the removal of soluble salts, the samples from the B horizon filtered more slowly than those of the A, but less difficulty was encountered than had been anticipated and that differences in filterability between the B and C horizon samples were not great.

DISCUSSION

The six profiles appear to possess all the morphological requirements of solodized solonetz, including the destroyed absorptive complex of the A horizon and the dense, black columnar B horizon. The exceptional features are the very low percentages of sodium and the very high percentages of magnesium in the exchange complex of the B horizon, calcium and magnesium ordinarily accounting for 90% of the total exchangeable bases and magnesium constituting one-half to two-thirds of them. Nikiforoff (10), who first studied the morphology of the profiles in the field, classified them as solonetz and assumed that exchangeable sodium was a dominant ion in the complex.

The few studies of solonetz and solonetz-like soils in the United States that include determinations of exchangeable bases show that sodium occupies a less prominent place in the complex than might be anticipated and that exchangeable magnesium makes up a rather high percentage. The exception to this is the Oklahoma soils reported by Murphy and Daniel (8) in which exchangeable sodium is a dominant ion. The maximum and minimum percentages of exchangeable magnesium reported in the different studies are shown in Table 9. The highest percentage, 76, was found in Minnesota profile 4 and the next highest, 66, in the San Luis Obispo sample reported by Kelley (5), while the lowest, 15, was in the exposed B horizon of farm E at Stillwater, Oklahoma. The percentage of exchangeable Na was highest, 56, in the same Oklahoma sample and lowest, 2, in Minnesota profile 6.

Whether or not the characteristic morphology of solonetz soils develops under the influence of Mg ions in the exchange complex does not appear to be established. As suggested by Kelley and Shaw (6), there is a possibility that such soils, even though Mg comprises a high percentage of the exchangeable bases, may have passed through a stage in which sodium was one of the dominant ions of the absorptive complex. A number of studies dealing with the effect of exchangeable Mg in the complex have appeared recently. Sushko and Sushko (13) saturated kaolin with Ca, Mg, and Na and determined the rate of filtration or permeability and found that the effectiveness of the ions might be expressed relatively as 100:70:1, respectively. By saturating solonetz soils containing Na with Mg they found the permeability to be markedly increased and conclude that Mg in the complex has only a limited effect as a peptizer and in this rôle stands

TABLE 9.—*Maximum and minimum amounts of exchangeable Mg reported for solonetz and solonetz-like soils of the United States.*

Description	Reported by	Percentage of total bases			
		Mg	Ca	Na	K
	California				
San Luis Obispo	Kelley	66	27	6	1
Pasa Robles	Kelley	40	49	10	1
	North Dakota				
Profile 11*	Kellogg	47	39	12	2
Profile 9	Kellogg	24	64	10	2
	Oklahoma				
Stillwater farm A†	Murphy & Daniel	27	32	37	4
Stillwater farm E	Murphy & Daniel	15	24	56	5
	Minnesota				
Profile 4	Author	76	19	4	1
Profile 6	Author	58	38	2	2

*Calculated from the sum of exchangeable Ca, Mg, Na, and K.
†1- to 12-inch section of exposed B horizon.

nearer Ca than Na and accordingly does not impart solonetz properties to the soil. They visualize the exchange mechanism as consisting of complexes relatively saturated with Mg, held in the surface very tightly to form a new type of Mg complex. This complex in turn might be dispersed by the action of Na and reflocculated by the removal of the Na by leaching, the latter being carried away before the more difficultly removable Mg. Such Mg would be able to play a part in exchange only after the Na has been removed.

Similarily, Uvarov and Kamlov (14) found that by saturating the illuvial horizon of four solonetz soils with Ca, Mg, and Na, the permeability was increased most by Ca, and that while Mg was not as effective, there was a very marked improvement as compared to the Na-saturated soil. The Mg was most effective as a coagulent in the soils having the most strongly developed solonetz properties. Saturation with Mg raised the moisture equivalent and increased dispersion somewhat, but in general the behavior resembled that of the Ca-saturated complex more closely than that of the Na-saturated one. From this they conclude that exchangeable Mg does not have much influence upon the solonetz character of soils.

Shavrygin (11) reports a study very similar to the two just mentioned in which the exchange complex of solonetz soils was saturated with Ca, Mg, and Na and the soils then studied with respect to permeability, hygroscopicity, water absorption, maximum water capacity, capillary rise of water, stickiness, degree of dispersion, and heat of wetting. His data show as in the other studies that in its effect on the soil Mg falls between Ca and Na. Since it modified the physical properties of the soil analogous to the absorption Na, although in a much less degree, it was concluded that the absorption

of Mg may control the solonetz characteristics if the latter are governed by such physical properties as were studied.

Kelley and Shaw (6, 12) have raised the question as to what constitutes a solonetz. The matter appears to resolve itself into the question of whether the morphological or chemical features or both are to be used as criteria. Ellis and Caldwell (3) suggest that a combination of both be used and that such designations as sodium solonetz and magnesium solonetz be employed. The present study demonstrates the occurrence of soils with morphology typical of solodized solonetz and having little or no greater amounts of exchangeable sodium present in the complex of the illuvial horizon than found in normal soils but having large amounts of exchangeable magnesium. If the suggestion of Ellis and Caldwell were followed they would be classed as magnesium solonetz. However, the question of whether or not these and other soils of similar character have developed under the influence of the magnesium ion in the absorptive complex has not been definitely answered.

SUMMARY

Samples from six soil profiles located in the southern part of the Minnesota portion of the Red River Valley and having morphological characteristics of solodized solonetz were examined. The soils were fine textured varying from silt loams to clays. The A horizon was found to be essentially free of soluble salts, but these were present in the B horizon where they increased in amount downward to reach a maximum in the C horizon. The A_1 horizon was acid in reaction in all cases and the A_2 in all but one case, while the B and C horizons were alkaline.

The total exchangeable bases decreased sharply in the A_2 horizon and rose again very sharply in the B horizon where, on the average, they reach a maximum and where they exceeded somewhat the amounts found in the C horizon. The exceptional features of the profiles were the very low amount of exchangeable sodium and the very high amounts of exchangeable magnesium found in the complex of the B horizon. Ordinarily the calcium and magnesium accounted for 90% or more of the exchangeable bases and of this the exchangeable magnesium comprised one-half to three-fourths. The average percentage of exchangeable sodium in the same horizon was approximately 3.0 and was lower than would be expected if the soils were classified as solonetz. Those for exchangeable magnesium, on the other hand, were much higher than would be anticipated This situation is contrary to the general conception of the development of solonetz soils under the influence of exchangeable sodium in the absorptive complex of the B horizon, but it is pointed out that the present condition does not preclude an earlier stage of development when sodium may have been a dominant ion in the complex.

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THE DIFFERENTIAL INFLUENCE OF CERTAIN VEGETATIVE COVERS ON DEEP SUBSOIL MOISTURE[1]

H. E. MYERS[2]

THE depletion of subsoil moisture by alfalfa has been studied during the preceding decade at both the Nebraska and Kansas Experiment Stations[3] where rainfall is frequently a limiting factor in crop production. The results obtained are so conclusive as to warrant the generalization that alfalfa growing on the soil for several years under conditions of limited rainfall reduces the available supply of moisture in the subsoil to depths much below the normal penetration of seasonal precipitation. Studies on this general problem have been continued by the Kansas Experiment Station. One phase which is herein reported deals with the influence of different legumes and non-legumes on subsoil moisture.

PLAN OF EXPERIMENT

For this investigation three adjoining series of plats located on the agronomy farm together with a nearby native grass pasture are utilized. Two of the series are devoted to rotations of legume, corn, and kafir (half the plat being planted to each), oats, and wheat, while the third is used for a rotation of corn, oats, and wheat. The legumes and length of time which they remain on the soil are as follows: Alfalfa, 2 years; biennial white sweet clover, 2 years; biennial white sweet clover, 1 year; and soybeans, 1 year. The legumes grown for 2 years as well as those grown for 1 year are compared directly and occupy adjacent duplicate plats. The experiment has been of sufficient duration that the rotation on all plats has now passed through one cycle and the second cycle is either completed or nearing completion, consequently a legume has been on each plat for either one or two periods. The years when legumes occupied the plats together with the annual rainfall for those years are shown in Table 1.

While the crop history of the cultivated land under consideration is not complete, it is thought that neither alfalfa nor sweet clover have been grown on the area previous to the present experiment. This conclusion is supported by the soil moisture data collected in this study. The moisture differences that occur between plats together with the regularity of these occurrences on duplicate plats strongly suggest that the subsoil moisture had not previously been depleted.

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[2]Assistant Professor of Soils: The author is indebted to Dr. M. C. Sewell, formerly of this department, for starting much of the field work which made this investigation possible and also to coworkers who have given helpful criticisms during the progress of the work and the preparation of the manuscript.

[3]DULEY, F. L. The effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron., 21: 224–231. 1929.

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TABLE 1.—*Annual rainfall for those years when legumes occupied the various plats.*

Year	Legumes 2 years			Legumes 1 year			
	Plats 1, 2, 11, 12	Plats 5, 6, 15, 16	Plats 7, 8, 17, 18	Plats 1, 2	Plats 3, 4	Plats 5, 6	Plats 7, 8
1927	37.45	—	—	37.45	—	—	—
1928	34.19	—	—	—	—	—	34.19
1929	—	—	33.63	—	—	33.63	—
1930	—	34.18	34.18	—	34.18	—	—
1931	—	38.75	—	38.75	—	—	—
1932	23.93	—	—	—	—	—	23.93
1933	21.94	—	—	—	—	21.94	—
1934	—	—	19.38	—	19.38	—	—
1935	—	—	16.81*	—	—	—	—

*Rainfall until August 1, a deficit of 2.91 inches. The average annual rainfall over a 43-year period has been 31.49 inches.

The soil was sampled by means of a tube equipped to go to a depth of 25 feet. Not all plats were studied this deep, since normally samples were taken only slightly deeper than the dry layer. Several pairs of plats scattered the length of each series were studied so that a direct comparison between two legumes could be made. Some of the plats sampled represent duplicate treatments. Three individual samples were taken from each plat. The data as presented constitute an average of these three readings unless otherwise stated. The samples were taken in foot sections on which both the moisture and moisture equivalent determinations were made. The moisture was determined by driving off the water at 110 C, while the moisture equivalent was determined by the centrifugal method. The samples that had been dried for the moisture determination were used for finding the moisture equivalent. It is recognized that the previous drying probably altered the true moisture equivalent, but since all samples were treated in the same manner, it is believed that the value of the results is not lessened.

The soil moisture was expressed finally as percentage of the moisture equivalent. This gives a figure which Conrad and Viehmeyer[4] designate "relative wetness". It was found that this method of expression overcame to a large extent differences due entirely to texture. This procedure was necessary because of the very abrupt and frequent changes in texture at the lower depths which made actual moisture figures too confusing to permit of satisfactory interpretation.

RESULTS OF EXPERIMENT

The experimental results are reported in Tables 2 and 3 and are presented graphically in Figs. 1 and 2.

In the interpretation of the data, a soil moisture content of 55% or less of the moisture equivalent is considered dry (at or near the minimum point of exhaustion), while soil with a moisture content of 70% or more of the moisture equivalent is considered to have been unaffected by crop removal.

The data in Table 2 make possible direct comparison of the differential effect on soil moisture of alfalfa and sweet clover both of which are allowed to grow continuously through two seasons. Data from

[4]CONRAD, JOHN P., and VIEHMEYER, F. J. Root development and soil moisture. Hilgardia, 4: 113–134. 1929.

TABLE 2.—*Moisture in the soil following alfalfa and sweet clover (each 2 years) expressed as percentage of the moisture equivalent.**

Depth of soil, feet	Plat number																	Non-legume rotation†
	1, 2 yrs. sweet clover	2, 2 yrs. alfalfa	5, 2 yrs. sweet clover	6, 2 yrs. alfalfa	7(a),† 2 yrs. sweet clover	8(a),† 2 yrs. alfalfa	7(b),‡ 2 yrs. sweet clover	8(b),‡ 2 yrs alfalfa	11, 2 yrs. sweet clover	12, 2 yrs. alfalfa	15, 2 yrs sweet clover	16, 2 yrs alfalfa	17(a),† 2 yrs sweet clover	18(a),† 2 yrs. alfalfa	17(b),‡ 2 yrs. sweet clover	18(b),‡ 2 yrs. alfalfa	Native grass sod§	
1	68.9	66.5	45.7	51.6	48.5	51.8	44.8	83.2	66.0	54.5	57.6	57.3	59.2	55.7	45.9	42.8	78.3	80.7
2	68.3	67.5	60.9	63.0	59.2	57.8	59.0	58.5	67.8	62.3	56.8	66.8	72.0	54.3	54.7	55.3	55.8	83.8
3	65.5	62.8	58.8	60.7	53.9	51.5	58.7	55.2	74.3	62.4	52.9	62.2	64.7	50.3	46.4	54.1	56.1	76.4
4	69.1	59.6	58.4	63.0	51.6	50.1	51.4	52.5	70.8	54.1	52.1	63.0	60.6	51.3	49.3	48.6	55.6	66.5
5	69.3	61.6	57.6	59.7	54.0	53.8	53.6	52.5	58.4	51.2	60.1	57.4	59.4	54.1	50.4	47.9	50.6	64.4
6	59.5	52.9	59.0	60.4	60.5	57.5	55.5	51.1	56.6	54.1	56.3	54.4	67.1	54.7	52.5	46.4	56.6	67.1
7	54.6	53.8	67.1	57.8	**68.9**	**64.5**	53.9	53.0	51.9	60.6	56.9	57.4	**69.4**	55.6	51.4	52.6	**64.6**	**65.1**
8	55.7	54.2	**69.4**	59.1	77.5	71.3	55.3	57.2	50.4	65.7	54.7	59.5	70.8	55.0	57.3	52.0	71.3	72.1
9	55.7	53.3	74.2	60.0	84.1	76.5	56.6	55.1	53.1	52.7	57.6	58.8	71.0	52.7	52.7	50.4	70.6	76.5
10	54.9	52.2	77.8	59.9	84.4	78.6	53.7	52.3	53.5	48.7	61.0	58.5	74.8	53.3	54.8	55.2	71.4	81.8
11	54.0	50.9	80.7	60.9	80.9	79.9	56.1	53.3	48.4	49.9	**66.9**	60.5	74.8	53.3	51.8	53.2	71.5	78.6
12	56.4	49.9	81.9	68.9	81.1	77.1	64.6	50.6	47.3	46.6	72.2	59.1	75.2	53.4	—‖	50.9	73.1	84.1
13	57.7	49.3	79.6	60.6	79.4	75.9	59.5	51.2	52.4	46.3	75.6	**65.5**	77.9	54.0	58.0	50.2	76.6	83.6
14	**61.9**	48.9	82.3	61.1	83.8	85.3	67.0	52.4	**58.2**	45.2	82.1	70.6	76.6	55.5	**62.0**	55.0	78.6	88.7
15	74.7	45.9	83.2	62.0	88.0	88.9	**65.0**	**57.6**	71.6	44.5	85.5	78.7	79.7	60.3	83.3	51.2	83.9	94.2
16	70.7	59.2	81.7	**68.7**	88.7	84.7	74.9	75.4	79.6	51.5	82.5	80.8	83.3	**68.9**	76.8	48.9	81.9	81.1
17	79.0	42.3	87.3	83.9	97.3	88.7	89.0	87.6	97.4	**65.2**	89.3	88.6	92.8	72.9	90.9	**49.8**	85.6	86.6
18	78.5	47.0	91.3	79.1	99.6	93.3	90.4	95.9	102.8	95.0	94.2	96.0	94.2	77.0	92.5	86.0	84.8	87.8
19	—	**67.2**	—	—	—	—	—	80.4	—	89.3	—	—	—	94.3	89.4	86.6	86.3	86.1
20	—	92.0	—	—	—	—	—	72.1	—	92.8	—	—	—	—	—	—	87.8	93.6

*The paired plats are to be compared directly since the legumes occupied the two areas during the same years Replication begins with No. 11 which is the duplicate of No. 1, plat 12 the duplicate of plat 2, etc.

†Average of two samples. Plats 7a, 8a, 17a, and 18a taken after the alfalfa and sweet clover had occupied the area for 2 years, but before the second seeding of these crops had become established.

‡Reading from one sample taken near the end of the second 2-year period of alfalfa and sweet clover.

§Average of four samples.

‖Lost.

an area devoted to a nonlegume rotation and from an area of native grass sod are included for comparison. In neither instance has the soil been reduced to dryness below the sixth foot. The results are shown graphically in Figs. 1 and 2.

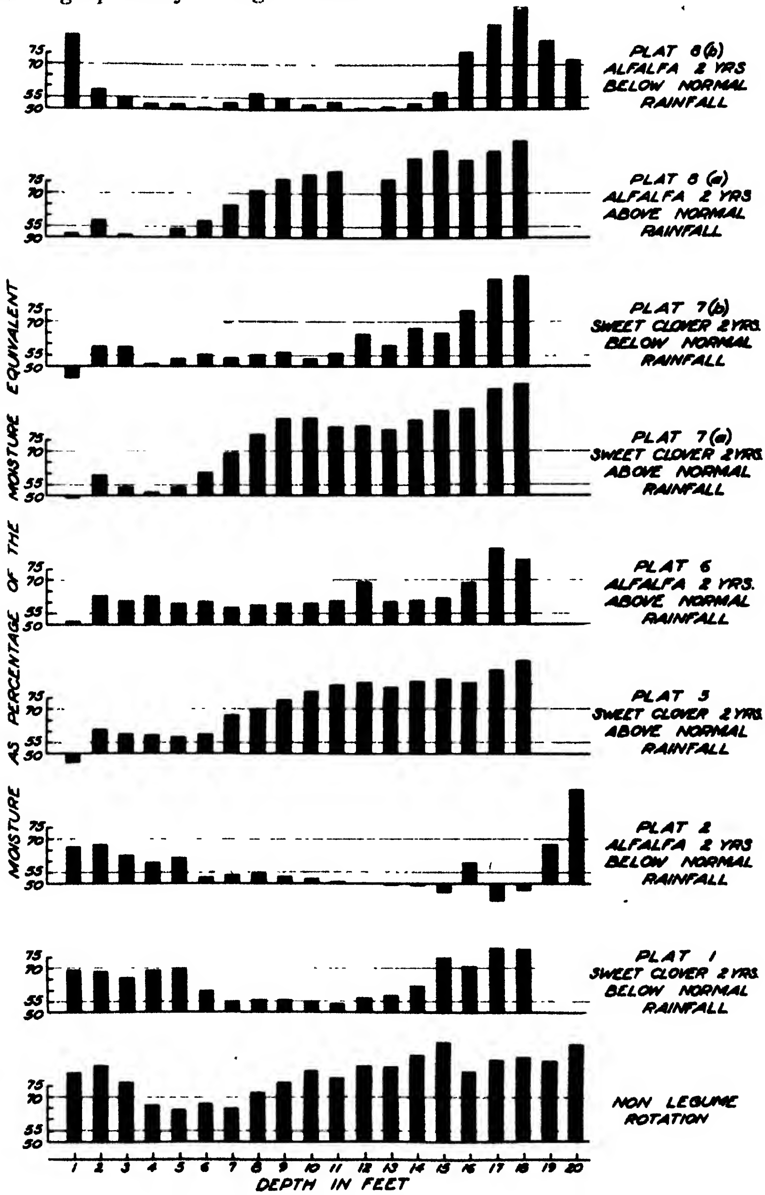

FIG. 1.—The comparative effect of alfalfa, sweet clover, and annual nonlegumes on deep subsoil moisture.

The soil moisture in both of the duplicate sweet clover plats, 1 and 11, was reduced below 70% of the moisture equivalent down to the fifteenth foot, while the adjoining alfalfa plats, 2 and 12, show reduction to the twentieth and eighteenth foot, respectively.

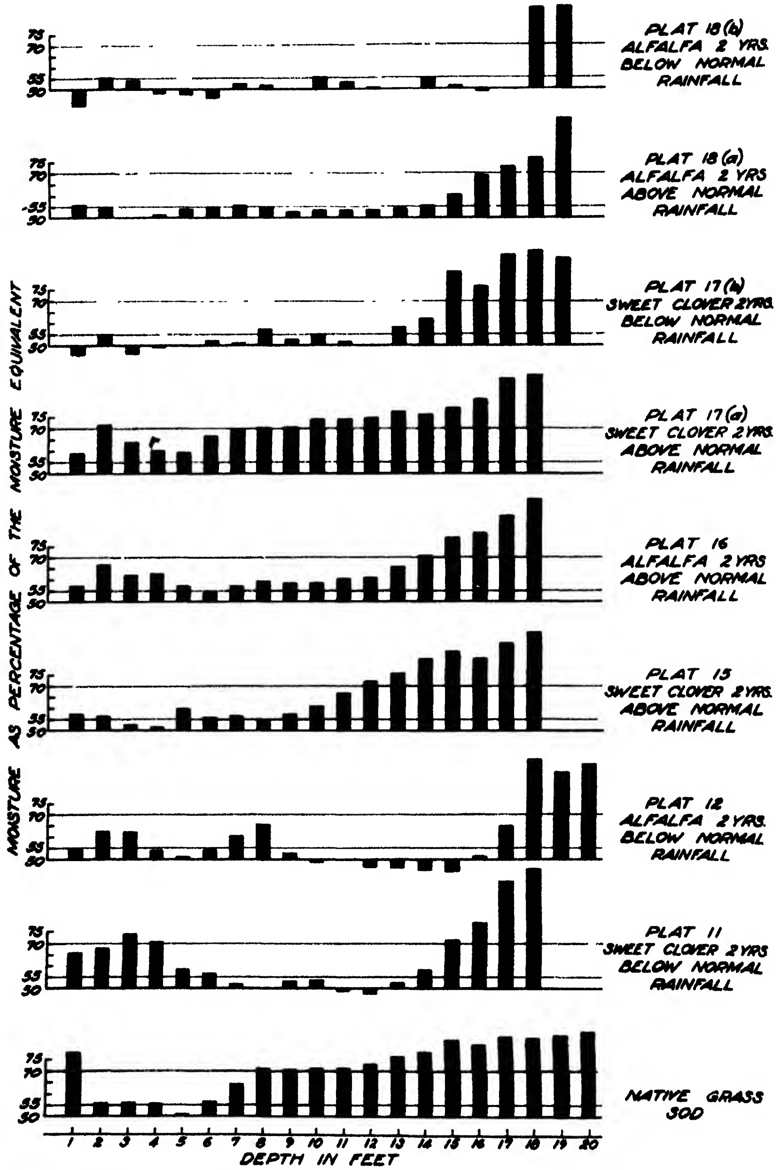

FIG. 2.—The comparative effect of alfalfa, sweet clover, and native grass sod on deep subsoil moisture.

TABLE 3.—*Moisture in the soil following sweet clover and soybeans (each 1 year) expressed as percentage of the moisture equivalent.**

Depth of soil, feet	Plat 1†, 1 year sweet clover	Plat 2‡, 1 year soy-beans	Plat 3, 1 year sweet clover	Plat 4, 1 year soy-beans	Plat 5‡, 1 year sweet clover	Plat 6‡, 1 year soy-beans	Plat 7, 1 year sweet clover	Plat 8, 1 year soy-beans	Non-legume rota-tion
1	73.3	77.3	56.9	70.6	66.7	75.2	74.9	67.4	83.2
2	71.1	75.0	57.8	62.5	57.0	60.5	64.8	62.5	75.6
3	60.9	70.6	56.5	55.9	53.0	56.6	59.8	62.3	67.9
4	60.8	69.9	57.1	52.1	52.1	53.6	60.7	63.0	70.4
5	67.6	65.1	58.8	54.2	51.2	55.0	60.6	66.4	72.8
6	69.7	73.0	58.7	57.4	49.4	60.0	59.2	66.0	72.5
7	69.6	73.4	58.8	64.8	54.6	65.6	50.3	68.2	78.9
8	71.7	74.0	52.9	73.9	54.8	73.0	52.7	67.8	85.9
9	74.4	76.4	55.5	77.1	57.4	79.7	60.6	65.5	84.2
10	77.5	84.7	64.6	79.2	70.3	84.9	70.4	81.6	86.1
11	—	—	68.4	—	—	—	85.3	—	88.5
12	—	—	87.6	—	—	—	87.0	—	91.8

*The paired plats are to be compared directly since the legumes occupied the two areas during the same year.
†Two cores only.
‡One core only.

In plats 5 and 15 the moisture was reduced much less than in plats 1 and 11. In plat 5 there was some reduction to the ninth foot but only slight reduction below the sixth foot, while in plat 15 there has been a lowering of the moisture content to the twelfth foot. The adjoining alfalfa plats, 6 and 16, show some reduction to the seventeenth and fourteenth foot, respectively. However, it can be noticed that the moisture reduction has not been as severe on these plats as on plats 2 and 12. The data indicate that on these areas the alfalfa has not reduced the moisture to the minimum point of exhaustion for the crop. On the sweet clover plats, 7 and 17, the moisture, during the first period of legume cover, has not been reduced below the seventh foot. On the corresponding alfalfa plats, 8 and 18, the reduction has been to the eighth and seventeenth foot, respectively.

When the sweet clover occupied plats 7 and 17 the second time a marked change was brought about in the deep soil moisture. During this period the reduction extended to a depth of 15 and 14 feet, respectively. During the same period the alfalfa on plat 8 reduced its moisture to the sixteenth foot. There is only a slight change in the moisture data for plat 18 for the two periods and the difference that does exist is probably due to sampling variation since it is doubtful if the roots of the second alfalfa crop could penetrate the dry layer formed by the first crop.

From the data presented it appears that sweet clover when allowed to make continuous growth for 2 years may, under certain environmental conditions, reduce the subsoil moisture to or close to the minimum point of exhaustion to a depth much below the normal seasonal penetration of rainfall. The maximum reduction under the conditions of this experiment has been 14 feet. This is in contrast to the results reported by Kiesselbach, Anderson, and Russel.[5] They

[5]*Loc. cit.*

state that "under sweet clover and red clover there was no significant moisture change below the sixth foot throughout the 5-year period."

In general, the depth of water removal for the experiment herein reported has not been as great with sweet clover as with alfalfa, but the apparent difference may be due to the variation in length of time the two crops occupy the soil. The alfalfa has the advantage of being established in the fall and also of growing after the sweet clover matures the second year. However, from a practical consideration the sweet clover is not as efficient in the utilization of deep subsoil moisture as the alfalfa, since the latter, which normally remains on an area for several years, will utilize the moisture to a considerably greater depth than the sweet clover. Sweet clover will possibly produce a dry layer of such magnitude as to make it impossible later for alfalfa to utilize the moisture at greater depths, whereas if the sweet clover were not included in the rotation this moisture could be used by the alfalfa.

The differential effect of both alfalfa and sweet clover on subsoil moisture in different seasons appears to be a direct function of the rainfall. In those years of marked deficiency of rainfall subsoil water was removed by both legumes to considerable depth, while on the other hand, during years of high rainfall deep subsoil moisture was depleted only slightly by both crops.

The data presented in Table 3 and Fig. 3 make possible a direct comparison of the influence of annual crops, including soybeans, 1 year sweet clover, and no legume, on subsoil moisture. On none of the soybean plats (2, 4, 6, and 8) has the moisture below the sixth foot been reduced to 55% of the moisture equivalent. While there has apparently been a reduction in the moisture by this crop, in some instances through the ninth foot, the reduction has probably not been of such magnitude as to prevent the roots of subsequent crops from penetrating this area.

On plats 3, 5, and 7 which supported sweet clover the soil has been reduced to near the minimum point of exhaustion through the ninth and eighth foot levels, respectively. There was apparently little or no reduction in the moisture content of the other sweet clover plat (plat 1). This probably was due to the more favorable rainfall during the periods of legume growth. A sample on plat 1 taken September 16, 1935, when sweet clover was again occupying the plat, indicated an almost complete drying to the eighth foot and a marked reduction through the ninth foot. The precipitation in the summer of 1935 was below normal.

From a practical point of view the reduction in subsoil moisture by 1 year of sweet clover may be of some importance when alfalfa production is to follow. This will probably be true if unfavorable rainfall conditions prevail during the interval intervening between the two crops. On the other hand, the depth to which water has been removed is not sufficiently great to preclude the possibility of renewal by seasonal rainfall. Penetration of water in the fall of 1935 on plat 5 reached into the ninth foot by November 1 which has eliminated the definitely dry layer that previously existed. This plat was plowed after oats harvest in preparation for wheat. On plat 3

where kafir was growing the penetration of moisture has been only to the eighth foot. In the latter plat a dry layer 2 feet in thickness remains.

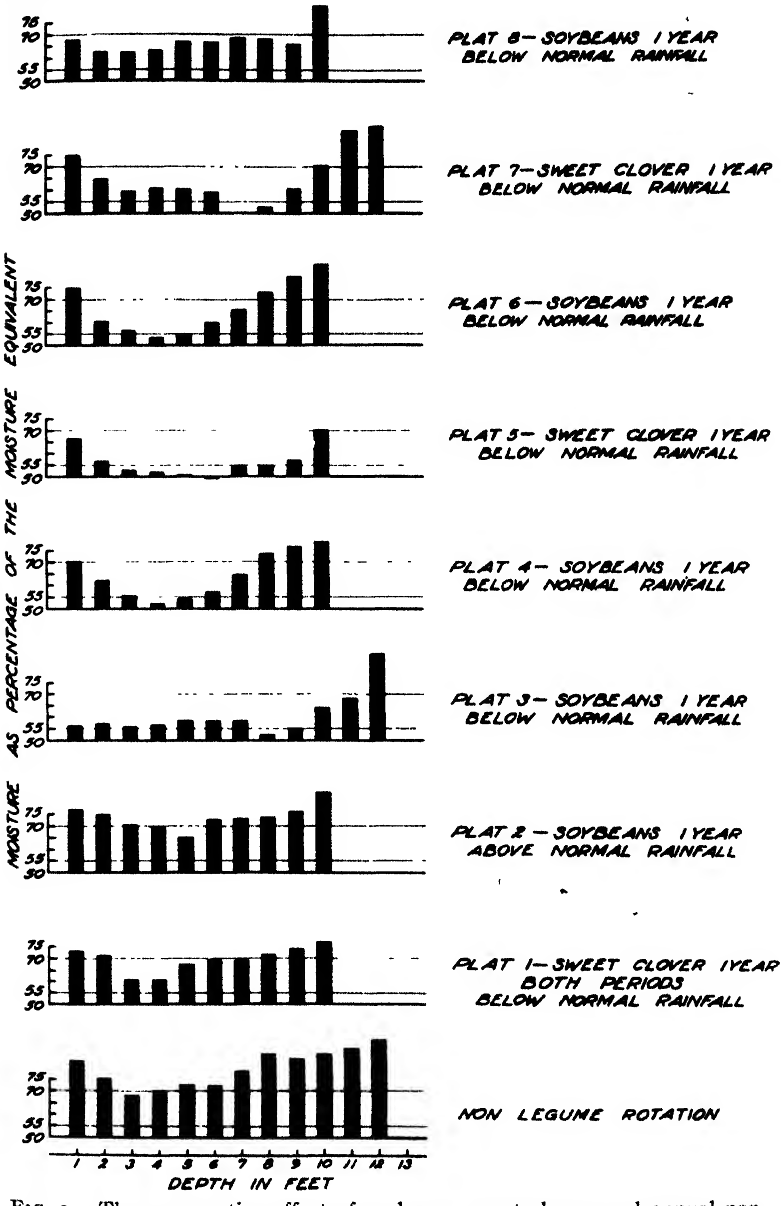

FIG. 3.—The comparative effect of soybeans, sweet clover, and annual non-legumes on deep subsoil moisture.

(Note: The legend for plat 3 should read sweet clover rather than soybeans.)

CONCLUSIONS

Sweet clover grown continuously on soil for two seasons under the condition of this experiment has reduced the subsoil moisture in certain instances to a maximum depth of 14 feet. The data indicate that a reduction approaching the minimum point of exhaustion has extended into the thirteenth foot section.

One year's growth of sweet clover in certain cases has reduced the moisture to near the minimum point of exhaustion to a maximum depth of 9 feet.

Soybeans growing for one season have not resulted in the development of a dry layer below the sixth foot in any plat included in this study.

The depth of the moisture reduction by alfalfa and sweet clover has been governed largely by the rainfall during the period when the legume occupied the soil.

The growth of sweet clover for either 1 or 2 years under limited rainfall conditions may result in the development of a dry layer of depth sufficient to prevent the utilization of moisture at a lower level by subsequent alfalfa crops.

RELATION OF FALLOW TO RESTORATION OF SUBSOIL MOISTURE IN AN OLD ALFALFA FIELD AND SUBSEQUENT DEPLETION AFTER RESEEDING[1]

C. O. GRANDFIELD AND W. H. METZGER[2]

THE work of Kiesselbach, Russel, and Anderson[3] and of Duley[4] has shown that alfalfa is capable of depleting the subsoil moisture to the point where the crop is dependent on current rainfall for its growth. Furthermore, under the soil and climatic conditions existing at Manhattan, Kansas, and at Lincoln, Nebraska, it has been shown that after the subsoil moisture is depleted by alfalfa it is not regained under continuous cropping even with comparatively shallow-rooted crops. With these facts in mind an experiment was undertaken in 1930 on a well-drained upland soil at the Kansas Agricultural Experiment Station to obtain information regarding the effect of fallow on the restoration of subsoil moisture. This experiment was planned to determine the rate of restoration of moisture during fallow periods ranging from 1 to 5 years and the rate at which this moisture was again depleted by a new seeding of alfalfa.

EXPERIMENTAL METHODS

A field which had previously grown alfalfa for 4 years was plowed in December, 1929, and the first soil samples were taken in March, 1930. One fallow plat was sown each year for 5 years, hence the fallow periods varied from 1 to 5 years and the subsequent cropping periods from 1 to 5 years.

The soil, a dark brown silt loam, is underlaid at a depth of 15 to 18 inches by a moderately heavy subsoil. The slightly weathered parent materials are encountered at a depth of 30 to 36 inches and are probably of loessial origin. The soil is relatively friable throughout the zone of root penetration of most crops and the deep subsoil, as judged from the appearance of the samples, is friable to a depth of 20 feet. Sand strata and pockets occur between the 10- and 20-foot levels. The subsoil in the 20- to 25-foot area is rather heavy.

Clean fallow was practiced on all the plats prior to seeding, all growth being killed by cultivation and the surface ridged so that practically no runoff occurred during the 5 years.

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[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No 252, Department of Agronomy. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 6, 1935.

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[3]KIESSELBACH, T. A., ANDERSON, A., and RUSSEL, J. C. Subsoil moisture and crop sequence in relation to alfalfa production. Jour. Amer. Soc. Agron., 26 : 422–442. 1934.

[4]DULEY, F. L. The effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron., 21 : 224–231. 1929.

Duplicate soil samples for moisture determination were taken on each plat in 1-foot sections to a depth of 25 feet at the beginning of the fallow periods, when the plants were sown, and at intervals after reseeding. The samples were placed in tin sampling cans, covered promptly, and taken to the laboratory where the moisture percentage was determined in the usual way. Duplicate moisture equivalent determinations also were made on each sample of soil. The wilting coefficient was then calculated as proposed by Briggs and Shantz.[5] It is fully realized that the wilting coefficient for a given soil calculated from the formula, wilting coefficient $= \frac{\text{moisture equivalent}}{1.84}$, may or may not represent the point at which a plant could be expected permanently to wilt growing on that soil. The wilting coefficient is merely used here as a physical constant with which to compare the moisture content of the soil as affected, at various depths, by the different treatments.

The data on rainfall during the experimental period are shown in Table 1. The precipitation for the first 2 years was above normal and for the last 3 years and 9 months below normal with a total deficiency for the 5¾ years of 15.88 inches.

TABLE 1.—*Monthly and annual precipitation at Manhattan, Kansas, 1930 to 1935.*

Month	1930	1931	1932	1933	1934	1935	Normal
Jan.	0.85	0.12	1.03	0.12	0.62	0.16	0.77
Feb	0.37	1.18	0.83	0.08	0.94	1.17	1.19
Mar	0.52	1.64	0.40	1.82	0.31	0.21	1.50
Apr.	6.72	2.79	1.91	2.86	0.52	1.07	2.78
May	5.23	3.28	2.67	1.57	4.17	7.65	4.33
June	6.39	2.80	4.88	0.69	1.89	6.51	4.62
July	0.57	1.52	1.91	4.68	0.85	0.04	4.53
Aug.	4.99	10.52	4.11	4.07	0.80	8.63	3.74
Sept.	2.43	7.21	4.03	4.13	4.66	4.88	3.39
Oct	2.86	2.04	0.60	1.03	0.63	—	2.29
Nov.	3.14	5.12	0.24	0.20	3.79	-	1.49
Dec	0.11	0.53	1.32	0.69	0.20	-	0.86
Total	34.18	38.75	23.93	21.94	19.38	—	31.49
Departure from normal	+2.69	+7.26	—7.56	—9.55	—12.11	+3.48	—

EXPERIMENTAL RESULTS

The data from representative plats 4 and 6 are presented in Table 2 and are shown graphically in Figs. 1 and 2 as gains and losses from the original moisture content of each foot, thus demonstrating the effect of fallow and of alfalfa cropping. Plat 4 was fallowed 18 months followed by 4 years of alfalfa, while plat 6 was fallowed 30 months followed by 3 years of alfalfa. The samples from all plats showed that the soil moisture fluctuated more in the first 2 feet and the lowest 5 feet than in the intervening area. The changes in the upper strata

[5]BRIGGS, L. J., and SHANTZ, H. L. The wilting coefficient for different plants and its indirect determination. U. S. D. A. Bur. Plant Ind. Bul. 230: 1–83. 1924.

TABLE 2.—*Percentage gains and losses of soil moisture as affected by fallow and alfalfa cropping.*

Depth, feet	Plat 4						Plat 6				
	Dec. 15, 1930, 9 mos. fallow	Aug. 25, 1931,* 18 mos. fallow	Nov. 18, 1932, 14 mos. alfalfa	Dec. 8, 1933, 27 mos. alfalfa	Dec. 21, 1934, 39 mos. alfalfa	Aug. 15, 1935, 48 mos. alfalfa	Dec. 18, 1931, 21 mos. fallow	Aug. 12, 1932,* 30 mos. fallow	Dec. 22, 1933, 15 mos. alfalfa	Dec. 21, 1934, 28 mos. alfalfa	Aug. 15, 1935, 36 mos. alfalfa
1	−0.1	−1.6	−9.3	−9.5	+1.8	+3.3	+5.9	+3.9	−7.7	+4.2	+7.0
2	+0.8	+1.3	−7.2	−7.0	−3.0	+2.5	+3.4	+0.5	−6.6	−3.5	+1.9
3	+1.7	+1.4	−5.1	−6.3	−7.1	+1.7	+1.1	−0.7	−8.1	−8.9	−2.0
4	+5.7	+6.1	−2.0	−3.2	−2.8	+1.7	+6.1	+4.4	−4.4	−4.4	−4.2
5	+7.0	+8.3	−1.9	−2.5	−2.6	−1.3	+3.9	+5.5	−5.4	−5.4	−6.1
6	+6.3	+7.8	−0.7	−2.9	−2.0	−2.5	+6.8	+6.0	−4.1	−4.6	−5.3
7	+3.7	+7.9	0.0	−2.2	−2.8	−2.4	+6.8	+5.5	−3.3	−3.9	−4.5
8	+6.1	+8.0	+2.9	−1.1	−1.9	−1.2	+7.4	+6.6	−1.4	−2.4	−3.2
9	+0.7	+7.1	+4.8	−1.8	−2.1	−2.6	+9.0	+7.7	−0.8	−1.0	−1.6
10	−3.8	+5.0	+3.4	−2.2	−2.2	−1.6	+6.9	+6.9	−0.8	−2.3	−2.6
11	−1.2	+1.5	+4.0	−1.5	−2.1	−2.5	+5.2	+4.9	−0.4	−3.2	−3.2
12	−0.6	−0.7	+2.3	−1.1	−2.7	−3.0	+3.1	+2.0	−0.8	−4.0	−4.2
13	−1.0	+0.2	+3.0	0.0	−2.6	−3.1	+4.2	+2.4	−0.1	−3.7	−4.0
14	+1.2	+1.0	+3.0	+0.2	−2.1	−2.9	+2.7	+2.4	+0.6	−3.7	−3.5
15	+0.5	+1.1	+5.1	+0.4	−2.0	−2.1	+1.6	+4.0	+1.6	−2.1	−2.1
16	+3.0	−0.6	−0.1	−2.9	−3.8	−3.9	0.0	+3.0	+1.2	−4.1	−4.2
17	−0.3	+3.6	+2.2	−0.2	+0.9	−0.7	0.0	+3.1	+0.4	−5.5	−6.2
18	−2.5	+0.7	+4.1	−3.1	−1.5	−2.5	+0.7	−0.4	+0.1	−6.5	−6.4
19	−1.6	+0.2	+4.3	−0.5	−1.2	−3.5	+2.2	+2.2	+2.9	−4.8	−6.1
20	−1.9	+1.6	+2.2	−0.5	−0.2	−0.2	+4.2	+3.6	+2.0	−7.3	−9.5
21	−3.2	−2.4	+2.1	−7.5	+4.2	+0.6	+5.6	+8.1	+2.0	−8.0	−11.0
22	+0.7	−1.8	+2.8	−4.3	−0.3	−2.2	+5.8	+8.3	+2.4	−6.3	−8.0
23	+2.6	+0.1	+1.0	−1.5	+1.8	−2.5	+6.1	+11.3	+2.5	+3.7	−4.2
24	−1.5	−0.4	−0.5	−1.8	−2.6	−3.2	+2.3	+1.0	+0.3	+0.9	−2.7
25	−0.4	+0.1	+1.1	+1.6	−0.8	−2.6	+1.0	+2.4	+3.9	−1.8	+0.4

*Seeded to alfalfa.

were due to differential moisture penetration from rainfall just previous to sampling, while the differences in the lowest 5 feet were probably due to the variability of ground water seepage.

Fig. 1, constructed from the data of plat 4, shows the rate at which changes in the moisture supply take place under different treatments.

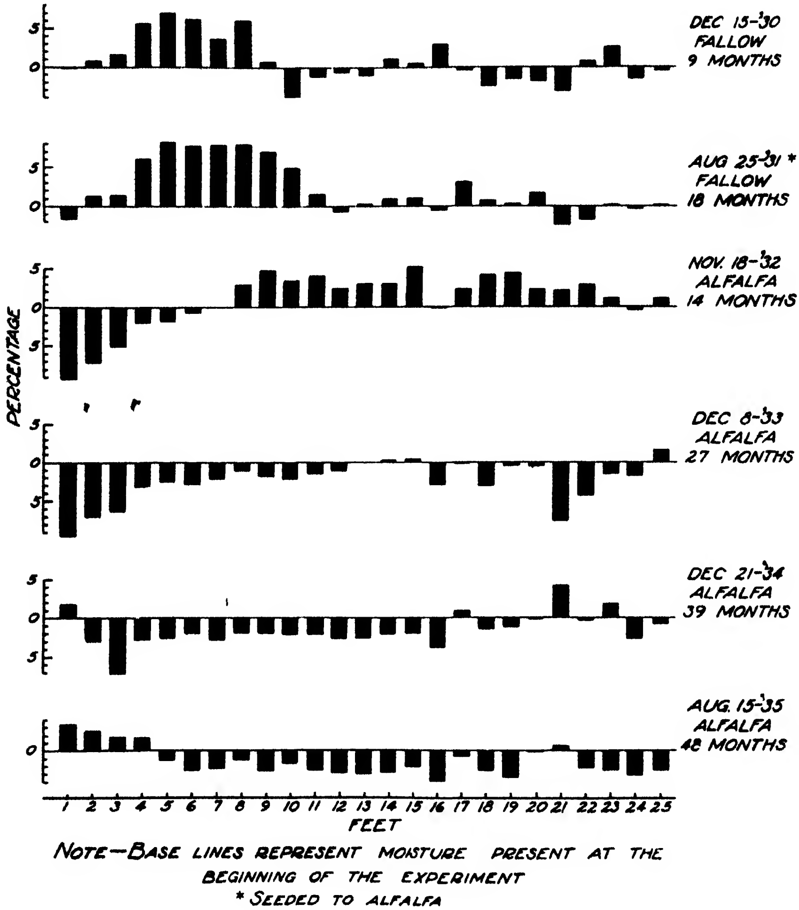

FIG. 1.—Gains and losses of soil moisture as affected by fallow and alfalfa cropping on plat 4.

As a result of 9 months of fallow the moisture increased to a depth of 8 feet as compared with the original moisture content with the exception of the first 2 or 3 feet which show the influence of a dry period at the time of sampling. After 18 months of fallow a further increase in moisture is noted to a depth of 11 feet, at which time alfalfa was sown, and 14 months later the moisture determinations showed that the new alfalfa had reduced the soil moisture below the original

moisture content to a depth of 8 feet. At the same time, however, there was an increase of moisture below 11 feet. It appears that part of the moisture accumulated from the 18 months of fallow had moved down while the new alfalfa roots evidently had not penetrated far enough to remove it. The moisture samples taken after 27 months

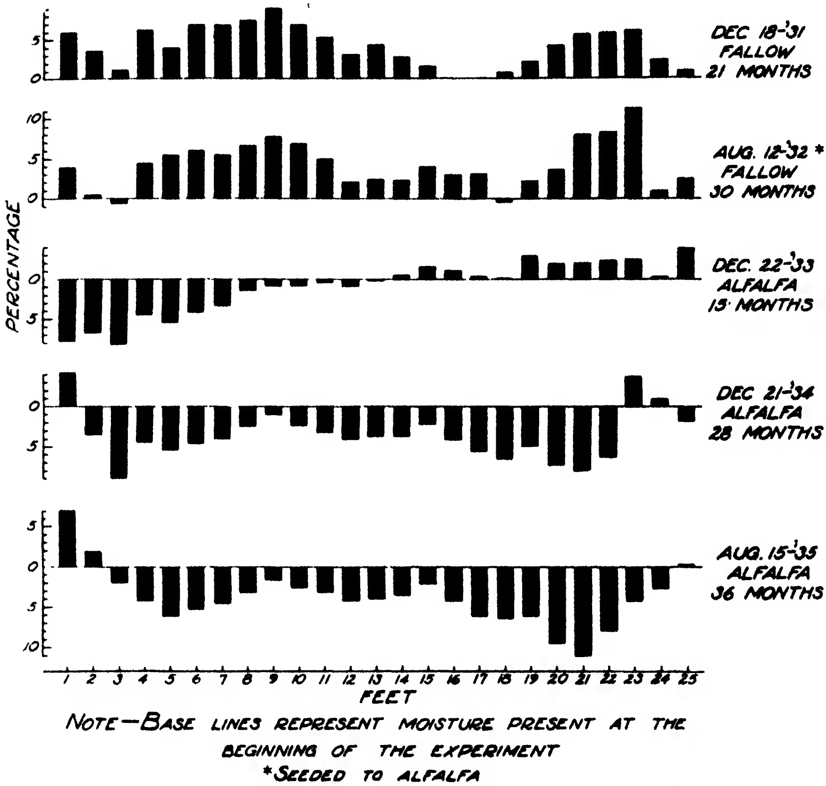

FIG. 2.—Gains and losses of soil moisture as affected by fallow and alfalfa cropping on plat 6.

of alfalfa cropping showed that the accumulated moisture was reduced practically to, or below, the original content at all depths. All subsequent samples on this plat showed similar results.

The data of plat 4 indicate that 18 months of fallow were not sufficient to produce an increase in the moisture of the subsoil below 11 feet. Fig. 2 shows graphically the data from plat 6 after periods of 21 and 30 months of fallow. These data indicate that a period between 21 and 30 months duration was necessary to obtain an increase in the moisture content at all depths. They also indicate that 15 months of alfalfa cropping removed the stored moisture to a depth of 12 feet and 28 months of cropping to a depth of 25 feet.

The physical properties of a soil influence its water-holding capacity and the thoroughness with which plants are able to remove the water.

Therefore, the extent of removal of available moisture was measured and the moisture content for each foot was compared to its wilting coefficient. It was found that the coefficient did not vary greatly from plat to plat for similar depths except in the lowest 5 feet, which again indicates the irregularity of the soil at this depth.

The data show that the soil had been depleted of its moisture by the previous alfalfa cropping to a point near or below the wilting coefficient to a depth of 20 feet. From the twentieth foot to the twenty-fifth foot, inclusive, there was a layer of soil that had a high moisture content indicating seepage from an underground source. The nineteenth foot was sandy and had the lowest wilting coefficient of any depth.

Table 3 shows the variations of the actual moisture contents as compared with the wilting coefficient for the various soil sections from plats 4 and 6. These data show the effect of the fallow and alfalfa cropping periods on the storage and removal of theoretically available moisture. Figs. 3 and 4 present the data graphically. The data for the first sampling date indicate that at the beginning of the experiment the amounts of moisture in all sections sampled with one exception were above the wilting coefficients. After 9 months of fallow (Fig. 3) the moisture available to the plants had increased to a depth of 9 feet, and after 18 months it had increased to a depth of 11 feet. Fourteen months of alfalfa cropping again removed this available moisture to a depth of 7 feet and in 27 months it had removed all available moisture to the wet layers found in all plats at, or below, 20 feet. In plat 6, as shown in Fig. 4, the moisture at the beginning of the experiment was not so nearly exhausted as in plat 4. As a result of 21 months of fallow a substantial increase in available moisture was obtained to a depth of 15 feet. After 30 months of fallow available moisture had increased in all depths. Fifteen months of alfalfa cropping took out all the accumulated moisture to a depth of 13 feet and 27 months removed the moisture completely to a depth of 21 feet, or to the more or less constantly wet area.

It is evident from the data given in Table 3 and presented graphically in Figs. 3 and 4 that as compared with the wilting coefficient the soil moisture increased as the fallow period increased, from 21 to 30 months being required for this increase to reach the 25-foot depth. The results also show the thoroughness with which the stored moisture was removed by a subsequent cropping of alfalfa, all the accumulated moisture being removed in 15 to 27 months of alfalfa cropping. This would indicate that after such removal the plants must depend largely on seasonal rainfall for their moisture supply except where roots had penetrated deep enough to reach moist soil at lower depths.

In the Nebraska work, cited previously, a 5-year period of fallow failed to restore the moisture removed below the 14-foot level by previous alfalfa cropping. The difference in the rate of restoration of subsoil moisture under fallow in the Nebraska experiments and the Kansas experiments emphasizes the importance of variability in soils and climatic conditions in determining the time required to restore the deep subsoil moisture.

TABLE 3.—*Percentage variation from the wilting coefficient of soil moisture as affected by fallow and alfalfa cropping.*

Depth in feet	Plat 4, treatment and date of sampling								Plat 6, treatment and date of sampling						
	Wilting coefficient	Initial, Mar. 15, 1930	9 mos. fallow, Dec. 15, 1930	18 mos. fallow, Aug. 25, 1931*	Alfalfa 14 mos. Nov. 18, 1932	Alfalfa 27 mos. Dec. 8, 1933	Alfalfa 39 mos., Dec. 21, 1934	Alfalfa 48 mos., Aug. 15, 1935	Wilting coefficient	Initial, Mar. 15, 1930	21 mos. fallow, Dec. 18, 1931	29 mos. fallow, Aug. 12, 1932*	Alfalfa 15 mos., Dec. 22, 1933	Alfalfa 27 mos., Dec. 21, 1934	Alfalfa 36 mos., Aug. 15, 1935
1	14.0	+10.3	+10.2	+ 8.7	+ 1.0	+0.6	+12.1	+13.6	13.6	+ 7.5	+13.4	+11.4	— 0.2	+11.7	+14.5
2	16.4	+ 9.9	+10.7	+11.2	+ 2.7	+2.9	+ 6.9	+12.4	17.5	+ 8.4	+11.8	+ 8.9	+ 0.8	+ 4.9	+10.3
3	16.2	+ 6.8	+ 8.5	+ 8.2	+ 1.7	+0.5	— 0.3	+ 8.5	16.5	+ 8.9	+10.0	+ 8.2	+ 0.8	0.0	+ 6.9
4	15.9	+ 3.1	+ 8.8	+ 9.2	+ 1.1	—0.1	+ 0.3	+ 4.8	15.5	+ 4.7	+10.8	+ 9.1	+ 0.3	+ 0.3	+ 0.5
5	15.4	+ 2.2	+ 9.2	+10.5	+ 0.3	—0.3	— 0.4	+ 0.9	15.0	+ 5.4	+10.3	+ 9.9	0.0	0.0	— 0.7
6	14.2	+ 2.5	+ 8.8	+10.3	+ 1.8	—0.4	+ 0.5	+ 0.1	14.2	+ 4.6	+11.4	+10.6	+ 0.5	0.0	— 0.7
7	14.4	+ 2.2	+ 5.9	+10.1	+ 2.2	0.0	— 0.6	— 0.2	13.9	+ 3.9	+10.7	+ 9.4	+ 0.6	0.0	— 0.6
8	15.0	+ 1.3	+ 7.4	+ 9.3	+ 4.2	+0.2	— 0.6	+ 0.1	13.8	+ 3.1	+10.5	+ 9.7	+ 1.7	+ 0.7	— 0.1
9	14.5	+ 1.3	+ 2.0	+ 8.4	+ 6.1	—0.5	— 0.8	— 1.3	14.3	+ 1.2	+10.2	+ 8.9	+ 0.4	+ 0.2	— 0.4
10	14.0	+ 1.4	— 0.4	+ 6.4	+ 6.4	—0.8	— 0.8	— 0.2	14.5	+ 1.3	+ 8.2	+ 8.2	+ 0.5	— 1.0	— 1.3
11	13.5	+ 0.7	— 0.5	+ 1.7	+ 4.7	—1.2	— 1.4	— 2.8	14.4	+ 1.4	+ 6.6	+ 6.3	+ 1.0	— 1.8	— 1.8
12	12.8	+ 1.3	+ 0.7	+ 0.6	+ 3.6	—0.2	— 1.4	— 1.7	13.7	+ 2.3	+ 5.4	+ 5.1	+ 1.5	— 1.7	— 1.9
13	12.3	+ 1.3	+ 0.3	+ 1.5	+ 4.3	—0.3	— 1.3	— 1.8	13.0	+ 2.2	+ 6.4	+ 4.6	+ 2.1	— 1.5	— 1.8
14	12.0	+ 0.7	+ 1.6	+ 1.7	+ 3.7	—0.9	— 1.4	— 2.2	13.2	+ 1.7	+ 4.4	+ 4.1	+ 2.3	— 2.0	— 1.8
15	11.8	+ 0.4	+ 0.9	+ 1.5	+ 5.5	—0.8	— 1.6	— 1.7	13.2	— 0.1	+ 1.5	+ 3.9	+ 1.5	— 3.2	— 2.2
16	12.5	+ 2.6	— 0.4	+ 2.0	+ 2.5	—0.3	— 1.2	— 1.3	12.6	+ 0.8	+ 0.8	+ 3.8	+ 6.0	— 3.3	— 3.4
17	13.4	— 0.8	— 0.5	+ 2.3	+ 1.4	—1.0	— 0.1	— 1.5	12.0	+ 2.8	+ 2.8	+ 5.9	+ 2.4	— 2.7	— 3.4
18	12.6	+ 1.1	+ 1.4	+ 1.8	* 5.2	—2.0	— 0.4	— 1.4	11.7	+ 3.6	+ 4.3	+ 3.2	+ 3.7	— 2.9	— 3.8
19	9.0	+ 2.9	+ 1.3	+ 3.1	+ 7.2	—2.4	+ 1.7	— 0.6	10.0	+ 3.6	+ 5.8	+ 5.8	+ 6.5	— 1.2	— 2.5
20	13.3	+ 1.6	— 0.3	+ 3.2	+ 3.8	—1.1	+ 1.4	+ 1.4	8.6	+ 7.3	+11.5	+10.9	+ 9.3	0.0	— 2.2
21	17.8	+ 8.4	+ 5.2	+ 6.1	+10.5	+0.9	+12.6	+ 9.0	8.2	+10.1	+15.7	+18.2	+12.1	+ 2.1	— 0.9
22	15.1	+11.9	+12.6	+10.1	+14.7	+4.6	+11.6	+ 9.7	9.8	+ 8.1	+13.9	+16.4	+10.5	+ 1.8	+ 0.1
23	12.7	+ 9.1	+11.7	+ 9.2	+10.1	+7.6	+10.9	+ 6.6	9.2	+ 6.5	+12.6	+17.8	+ 9.0	+10.2	+ 2.3
24	9.3	+ 8.0	+ 6.5	+ 7.6	+ 7.5	+6.2	+ 5.4	+ 4.8	9.9	+ 6.5	+ 8.8	+ 7.5	+ 6.8	+ 7.4	+ 3.8
25	9.5	+ 8.2	+ 7.8	+ 8.3	+ 9.3	+9.8	+ 7.4	+ 5.6	11.0	+ 7.5	+ 8.5	+ 9.9	+11.4	+ 5.7	+ 7.9

*Seeded to alfalfa.

SUMMARY

In experiments conducted at Manhattan, Kansas, it was found that alfalfa cropping had depleted the soil of available moisture to a depth of nearly 25 feet. Clean fallow restored the available subsoil moisture to a depth of 25 feet in approximately 2 years and a subsequent seeding of alfalfa again depleted this moisture in about the same length of time. The conclusion is drawn, therefore, that 2

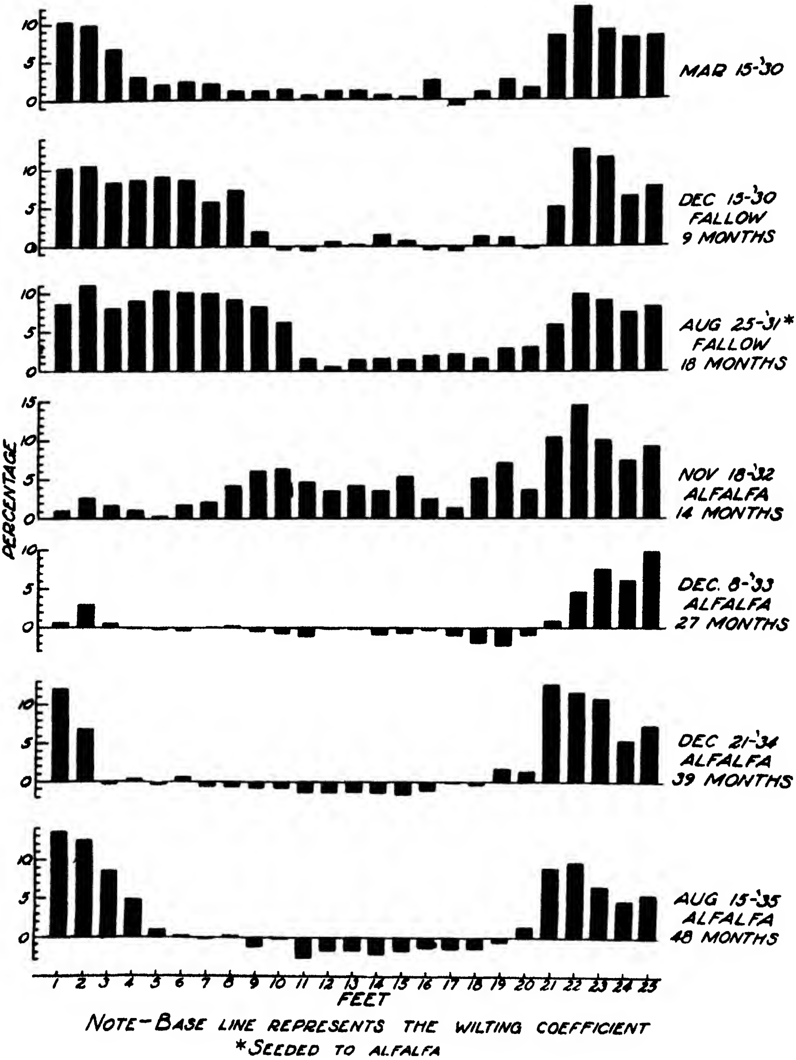

FIG. 3.—Variation of soil moisture from the wilting coefficient as affected by fallow and alfalfa cropping on plat 4.

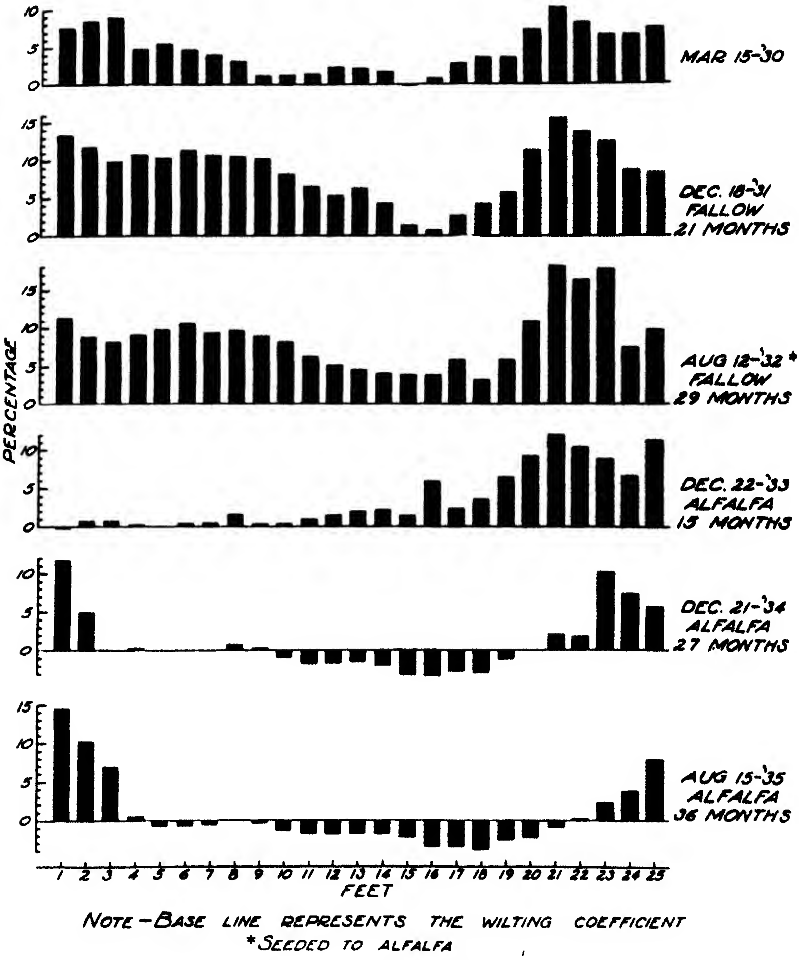

FIG. 4.—Variation of soil moisture from the wilting coefficient as affected by fallow and alfalfa cropping on plat 6.

years of fallow were necessary to restore subsoil moisture on old alfalfa ground to a point where the roots of a newly seeded crop could penetrate through moist soil to a depth of 25 feet or more. Two years after seeding alfalfa the subsoil was depleted of moisture to a point near the wilting coefficient, making it necessary for the crop to depend on current rainfall, unless the root penetration had been deep enough to reach moisture at lower depths.

THE RELATION OF SOIL MOISTURE TO PEAR TREE WILTING IN A HEAVY CLAY SOIL[1]

R. A. WORK AND M. R. LEWIS[2]

THE conclusions reached by various workers as to the availability to plants of soil moisture above the permanent wilting percentage as defined by Hendrickson and Veihmeyer (9)[3] differ rather definitely. In this report further evidence in support of the conclusion that all moisture above that point is not equally available is presented and a hypothesis supporting this conclusion, heretofore presented by Vasquez (16), Magness (13), and Lewis, Work, and Aldrich (12), is further amplified.

Bartholomew (5) says, "The leaves themselves may not wilt until the wilting coefficient of the soil has been reached, but the fruits may begin to suffer long before." He concluded that the root system of a lemon tree, even with highly available soil moisture, is unable to afford the fruit enough water to prevent suffering of the fruit during periods of high transpiration opportunity.

Furr and Degmen (7) report that, "The data . . . indicate that the relative amount of available soil moisture had a measurable, though slight, influence on fruit growth and a marked influence on stomatal behavior while the soil moisture is several per cent above the wilting percentage."

As a result of studies of the irrigation requirements of pear trees, Aldrich and Work (1) and Lewis, Work, and Aldrich (12) found that differential amounts of soil moisture within the available range exert a profound influence upon pear fruit size and consequent yield. Aldrich and Work (2) have also shown that soil moisture variations within the available range influence the amount of fruit bud formation.

With pear trees in heavy clay soil the senior author found (20) that during periods of relatively uniform weather conditions moisture is lost from all soil depths at a decreasing rate as the moisture content decreases, beginning, ordinarily, when from 50 to 60% of the available soil moisture is still present.

The conclusions of this group of workers may be summarized by the statement that fruit trees may suffer for water, as evidenced by slowing up in the growth rate of fruit and by decrease in the rate of extraction of soil moisture, long before the moisture content of the soil of any material portion of the root zone is reduced to the permanent wilting percentage

On the other hand, other workers conclude that soil moisture above the permanent wilting percentage is readily available to plants and that trees do not

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[1]This paper is a report of investigations initially conducted under a cooperative agreement between the Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, and the Soils Department, Oregon Agricultural Experiment Station, and later with the additional cooperation of the Bureau of Plant Industry, U. S. Dept. of Agriculture. Published as Technical Paper No. 241 with the approval of the Director as a contribution of the Medford Branch of the Oregon Agricultural Experiment Station, Medford, Ore. Received for publication December 9, 1935.

[2]Associate Irrigation Engineer, Division of Irrigation, Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, and Irrigation Engineer, Soils Department, Oregon Agricultural Experiment Station and Division of Irrigation, Bureau of Agricultural Engineering, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 134.

suffer until the soil of some part of the root zone is reduced to approximately the permanent wilting percentage.

Hendrickson and Veihmeyer (9) and Veihmeyer and Hendrickson (18) define "permanent wilting percentage" as the soil moisture condition at which plants wilt and do not recover unless water is applied to the soil. They hold that the permanent wilting percentage is a narrow range of soil moisture content within which wilting takes place. They define "readily available moisture" as the entire range of soil moisture between field capacity and approximately the permanent wilting percentage.

Hendrickson and Veihmeyer (10) say, "The substantially uniform extraction rate between the field capacity and the permanent wilting percentage indicates that prune trees can obtain water with equal facility from the field capacity to about the permanent wilting percentage."

Taylor, Blaney, and McLaughlin (15) state that, "it appears that soil moisture is readily available to well established plants down to the wilting coefficient as defined by Briggs and Shantz." They define the "ultimate wilting point" as the condition of the plant when *all* the leaves are wilted. Their "ultimate wilting point" is slightly lower than the criterion of wilting we have used at Medford, since usually we did not wait for the apical leaves of the plants to wilt.

Veihmeyer and Hendrickson, and Taylor, Blaney, and McLaughlin as well, recognize a visible range of plant suffering due to a water deficit, but neither group appear to have observed that period when, although the water content of the soil, as nearly as it can be measured by the usual methods of sampling, is well above the permanent wilting percentage, such tree responses as time of stomatal opening and rate of growth of fruit and twigs are reduced by reason of a water deficit in the plants, which latter in turn may be traced to a deficiency in soil moisture.

Gradually an explanation of these apparently contradictory views has been formulated. Vasquez (16) points out that on days of high transpiration opportunity the plants may suffer even if there is still available water in the soil and offers the hypothesis that at such times only the zone of soil immediately surrounding the roots is dry and the rest still holds available water. Magness (13) expresses very clearly the opinion which Aldrich and Work (1), Lewis, Work, and Aldrich (12), and Work and Aldrich (21) had come to independently that the slow capillary movement and sparse root population in heavy soils as compared to lighter soils so slowed up the absorbtion of water by the roots that trees might suffer before the moisture content of the soil of any zone large enough to be sampled by customary methods was reduced even approximately to the wilting point.

Furr and Magness (8) found a marked difference in the daily period of stomatal opening and the rate of growth of apples between irrigated and non-irrigated plats when "on the basis of the average condition of soil moisture the dry plat was appreciably above the wilting percentage", but go on to say, " it is highly probable, however, that localized soil areas containing a fairly high root population were reduced to the wilting percentage at this time."

It appears from the above quotation that in 1930 Furr and Magness were still thinking in terms of comparatively large bodies of soil

In many of the studies heretofore reported the evidence of suffering on the part of the trees and the intensity of soil sampling have been such as to leave some doubt as to the proof of suffering while all parts of the root zone held water above the wilting point. At Medford, Ore., unmistakable evidence of extreme suffering of pear trees has been

observed when intensive soil sampling showed that all parts of the root zone held available water. The term "sample average" is used herein to designate the moisture content of any one particular soil sample 7/8 inch in diameter taken from 1 foot depth of soil at any level. Those observations and a suggested explanation are reported herewith.

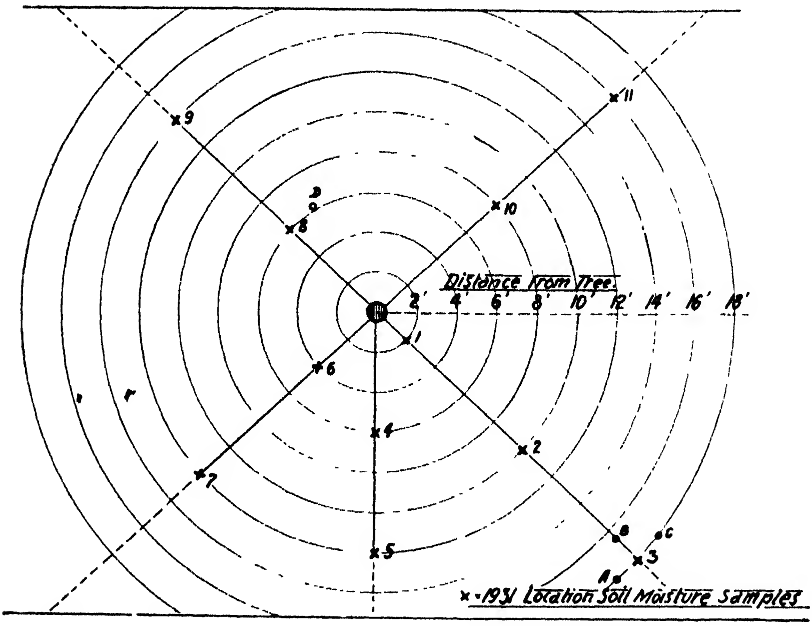

FIG. 1.—Sampling locations, tree E4, 1931.

TREE AND SOIL USED

In 1931, tree E4 in the Klamath orchard (11) near Medford, an Anjou pear tree on French root stock, was 26 years old, with a trunk circumference of 68.7 cm and an average limb spread of about 12.4 feet. The soil is Meyer clay adobe, a nearly black clay of pronounced adobe structure, bedded on shale at a depth of 4 feet.

SOIL SAMPLING METHODS

The 11 sampling locations, all within the root zone of tree E4, are shown in relation to the trunk of that tree in Fig. 1. Samples were taken with the soil tube from the underside of the mulch to bedrock and the moisture content of each foot depth of each hole was determined at each date of sampling. Moisture contents are reported on the dry weight basis. Sampling started May 12, 1931, and terminated on December 8 of the same year. Between May 12 and September 15 the average interval between sampling dates was 10 days.

PERMANENT WILTING PERCENTAGE DETERMINATIONS

Determinations of the permanent wilting percentage were made in 1932 for each foot depth at each of four sampling locations, *viz.*, Nos. 3, 7, 8, and 11. Samples for wilting percentage determinations were taken at a 1-foot offset from the regular sampling locations, and the soil was prepared and determinations were made by methods described by Work and Lewis (19). A summary of these determinations, each of which is an average of eight individual tests, is shown in Table 1.

TABLE 1.—*Wilting percentage for each foot depth at four locations in root zone of tree E4, Klamath Orchard, 1932.*

Sampling location*	0-1%	1-2%	2-3%	3-4%
3†	18.2	19.3	17.7	—
7‡	13.1	15.5	14.5	15.6
8‡	12.4	15.0	14.1	13.3
11†	12.0	16.1	15.7	13.5

*See Fig. 1.
†Determinations made in March, April, and May, 1932, under greenhouse conditions. Humidifier used
‡Determinations made in August, September, and October, 1932, under outside growing conditions. Humidifier used.

It will be noted on examination of Table 1 that there is a wide difference between the permanent wilting percentage for hole 3 and for holes 7, 8, and 11 at all depths. The reason for this is somewhat speculative. Conditions under which the plants were grown might account for some of the difference. Plants in soil from location 3 were grown in a greenhouse during early spring and were not as vigorous as the plants grown outside in the late summer in soil from locations 7, 8, and 11. The average top green weight of the 19 plants growing in soil from location 3 was 1.8 grams at the time of wilting, but the average top green weight for 71 plants growing in soil from locations 7, 8, and 11, was 2.3 grams. These latter more vigorous plants probably made more extensive root growth and therefore would be likely more completely to use all the available moisture in the soil of the container. Visible root population of even the most thrifty sunflower plants, is relatively sparse in these heavy clay soils. On the other hand, some variation of soil texture or structure at location 3 may have caused a higher permanent wilting percentage value there.

In order to determine if this were the case, additional wilting percentage determinations were made in 1935 for each foot depth to 4 feet at each of four locations. Holes A, B, and C were 1½ feet northeast, 1½ feet southeast, and 1½ feet southwest, respectively, of sampling location 3. Hole D was 1½ feet southwest of sampling location 8, as shown in Fig. 1. Determinations of the "permanent wilting percentage" were made by V. C. Hill at Oregon State College. Table 2 is a summary of these determinations each of which is an average of eight individual tests. Determinations were made in March and April 1935 under greenhouse conditions.

The average permanent wilting percentage representing holes A, B, and C, all within a radius of 1½ feet of hole 3, is lower at every depth

TABLE 2.—*Wilting percentage for each foot depth at four locations in root zone of tree E4, Klamath Orchard, 1935.*

Sampling location*	0–1%	1–2%	2–3%	3–4%
A	14.5	16.8	16.7	17.0
B	14.8	16.5	17.5	17.5
C	14.0	16.6	16.8	17.3
D	14.1	15.8	16.5	16.9
Average of A, B, C	14.4	16.6	17.0	17.3

*See Fig. 1 for location.

than that of hole 3. This would indicate that the less vigorous plants grown on soil from location 3 in 1932 did not reduce the soil moisture in those samples to as great a degree as more vigorous plants grown in the late spring of 1935 on soil from adjacent sample locations.

The average permanent wilting percentage for locations A, B, and C determined in 1935 is substituted for the values determined in 1932 for location 3. In the subsequent discussion the average permanent wilting percentage for tree E4 is assumed to be the average of values for holes 7, 8, and 11 and the A, B, C average. Those values are: 0–1, 13.0%; 1–2, 15.8%; 2–3, 15.3%; and, 3–4, 14.9%.

Examination of the data shows the wilting percentage as determined in 1935 for all depths at location D (1½ feet distant from location 8) to range from 0.8% to 3.6% higher than those of samples from location 8 determined in the fall of 1932 No ready explanation for this difference offers. The two sets of determinations were made under differing environmental conditions by separate workers. Some variation of soil texture at location 8 may have caused higher values at every depth there. However, since the values found at location 3 in 1932 are out of line both with the values found later in 1932 and in 1935 and because environmental conditions for determinations made on samples from that location differed from those prevailing for determinations made at locations 7, 8, and 11, we feel justified in discarding the values obtained in 1932 for hole 3. Whether determinations of the permanent wilting percentage made at location D in 1935 or those made at location 8 in 1932 represent the true values for that sector of the root zone of tree E4 is not particularly important, as will be shown in subsequent discussion.

SOIL MOISTURE DATA

The soil moisture content of each foot depth in each sampling location is shown for several dates in Table 3 and the average for each foot is plotted on Fig. 2 for the period July 18 to November 2, 1931.

RESULTS AND DISCUSSIONS

On August 17, 1931, no trees in plat E of the Klamath Orchard appeared wilted. On August 19, 1931, it was noted that trees E2, E3, and E4 were badly wilted. No spray burn or red spider damage could be observed on these trees. On August 23 it was noted that other nearby trees were showing wilting. On August 24 pressure tests were made on 22 fruits from plat E. Eleven fruits were taken at random

TABLE 3.—*Soil moisture contents on a dry weight basis, tree E4, late summer, 1931.*

Location No.	Aug. 4, %	Aug. 19, %	Aug. 27, %	Sept. 15, %	Oct. 14, %
			0 to 1 Foot		
1	16.9	16.7	14.5	15.8	14.6
2	22.1	22.0	21.0	21.2	16.5
3	25.5	22.5	16.8	20.2	17.1
4	20.2	15.2	16.1	17.2	15.1
5	22.3	18.3	16.8	15.7	16.2
6	15.8	13.6	16.3	14.5	15.1
7	20.2	16.4	17.4	17.7	16.8
8	17.3	20.2	13.8	15.7	15.2
9	21.2	17.4	16.5	18.4	15.7
10	20.8	19.1	14.8	14.8	12.5
11	23.6	18.6	17.7	16.5	15.4
Average	20.5	18.2	16.5	17.1	15.5
			1 to 2 Feet		
1	18.5	18.4	17.8	17.5	17.5
2	22.8	22.7	22.6	19.8	22.1
3	22.3	18.9	18.7	21.2	17.3
4	19.9	17.2	18.7	18.0	18.6
5	23.3	22.0	18.0	17.1	17.5
6	18.0	16.7	16.7	16.3	17.3
7	22.7	17.9	18.2	19.0	19.0
8	19.6	23.1	20.6	17.9	19.2
9	21.6	20.2	20.2	22.9	22.3
10	23.8	21.1	16.9	16.6	15.9
11	24.2	22.8	19.1	18.8	20.1
Average	21.5	20.1	18.9	18.6	18.8
			2 to 3 Feet		
1	18.9	19.6	17.8	16.9	18.0
2	21.4	20.4	19.5	16.9	20.8
3	20.1	19.3	18.4	15.5	18.0
4	19.1	17.9	18.2	18.5	18.8
5	20.5	20.2	23.6	17.0	16.5
6	21.3	17.6	16.6	16.7	17.0
7	22.9	17.6	18.5	18.3	18.4
8	23.6	18.0	18.1	15.8	17.9
9	25.0	23.0	22.9	17.8	22.0
10	26.4	23.0	19.4	20.4	18.4
11	23.6	23.4	21.1	18.8	18.9
Average	22.1	20.0	19.5	17.5	18.6
			3 to 4 Feet		
1	——	15.9	17.1	17.3	17.4
2	——	——	15.6	——	——
3	19.0	——	——	14.8	——
4	18.5	16.7	16.0	16.4	17.6
5	15.5	17.8	14.4	16.0	12.4
6	16.6	14.1	16.1	14.5	14.8
7	17.4	17.7	15.5	15.2	15.8
8	21.4	18.4	16.0	14.0	19.1
9	22.4	22.2	21.1	18.0	19.1
10	25.6	18.8	16.3	16.0	17.5
11	19.4	21.5	17.7	17.8	18.9
Average	19.5	18.1	16.6	16.0	16.9

from unwilted trees, seven from trees E2 and E3 which were wilted (at 7 a. m.), and four from tree E4 which was badly wilted and about one-third defoliated. Flesh firmness by the Oregon type of tester for the three lots was as follows: 23.7 pounds, 25.1 pounds, and 25.9 pounds, respectively. The firmness of the fruit from the wilted trees was higher than that from the unwilted trees.

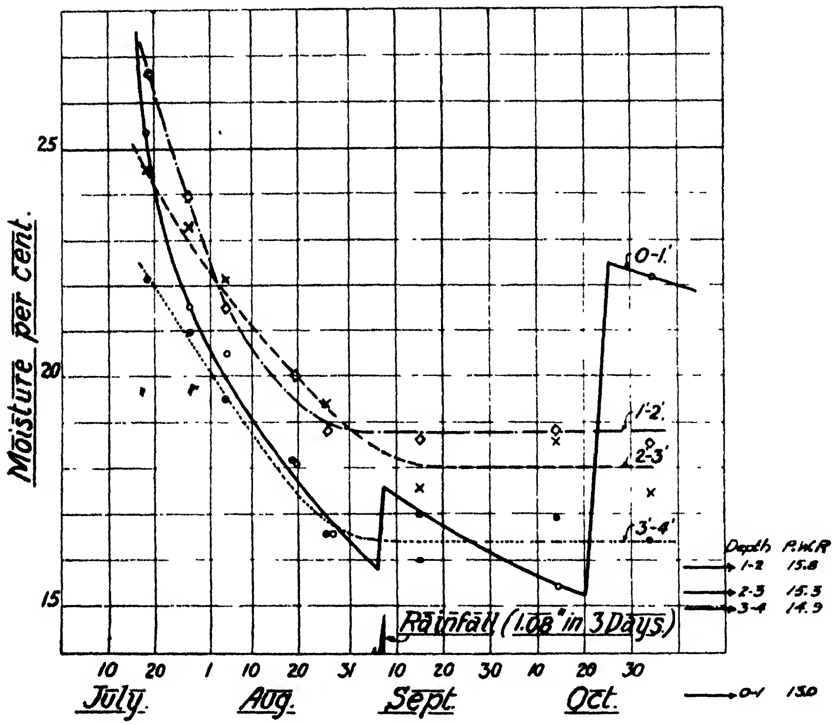

FIG. 2.—Soil moisture content, tree E4, 1931.

It appears that on the wilted trees a water deficit in the leaves resulting from transpiration withdrew water from the fruit, and by toughening of the cortical cells increased the pressure required for penetration of the pressure tester plunger. In the case of citrus Bartholomew (5) points out that detached lemons will not decrease in volume as much as fruit on detached limbs. Chandler (6), working with peaches, grapes, cherries, and small fruits, found that water would move from the fruit to the leaves, causing shrivelling of fruit if the water supply to the leaves became limited. These references are cited and data on pressure tests given as further indication of the acute condition of wilting reached by the tree on August 24.

This tree first showed visible wilting of the leaves on August 19, yet on that date the average soil moisture content of each foot level was several per cent above the average permanent wilting percentage for that level. Of the 42 determinations of soil moisture made that day only 2, namely, hole 6, depth 0 to 1 foot, and hole 6, depth 3 to

4 feet, showed moisture contents as low as the average permanent wilting percentages for their respective depths. The average soil moisture contents of the first, second, third, and fourth feet were 5.2, 4.3, 4.7, and 3.2 %, respectively, above the average permanent wilting percentages for the corresponding depths. On this date the tree was still extracting moisture from the soil at nearly a normal rate as will be seen from an inspection of Fig. 2.

However, except for the first foot, extraction of moisture had materially slowed down by August 27, yet the average moisture content of none of the upper 4 feet, containing almost all of the roots (4), had reached the permanent wilting percentage. Examination of Table 3 shows that on that date of the 43 soil moisture samples from 11 locations and four depths in the root zone of tree E4, in only one, namely, hole 8, depth 0 to 1 foot, had the soil moisture reached the permanent wilting percentage. The average moisture contents of the first, second, third, and fourth feet were 3.5, 3.1, 4.2, and 1.7%, respectively, greater than the permanent wilting percentages of the respective depths.

Rate of moisture extraction decreased rapidly at all levels, except the first foot, after wilting occurred, and by September 15 had ceased. Based on the rate of soil moisture extraction rather than on observed tree response, all levels except the first foot had reached the lower limit of availability by the later date. Withdrawal from the second foot ceased at about 19%, from the third foot at about 18% and from the fourth foot at about 16%, these percentages being 3.2, 2.7, and 1.1 higher than the permanent wilting percentages for the corresponding depths.

Taylor, Blaney, and McLaughlin (15) refer to such curved lines of extraction by stating that "any flattening of curves showing average rate of extraction of soil moisture must be taken as evidence that some portion of the root zone has approached the wilting range." The evidence herewith presented does not necessarily contradict that statement because we have so far been unable to show the moisture content of soil directly in contact with absorbing root surface. However, so far as our present technique of soil sampling for moisture content can determine, we have found the rate of loss of soil moisture to decline progressively, beginning long before the average soil moisture content of any portion of the root zone large enough to sample has approached the permanent wilting percentage.

Unpublished studies by the authors of the rate of infiltration and penetration of irrigation water on this soil show that the rate of downward movement is very slow. This fact, together with the general character of the soil, make it reasonable to assume that lateral movement of moisture by capillary action is also very slow. McLaughlin (14), Veihmeyer and Hendrickson (17), and others have shown that the rate of movement of moisture by capillary action from moist to dry soil is too slow through any large distance to supply the needs of plants.

Observations on visible small roots in several pear orchards at Medford (4) have shown that in these heavy clay soils the roots do not occupy the entire soil mass.

These facts and the results of the work at Medford seem to lead to the following explanation of the different conclusions cited at the beginning of this paper.

The roots first extract moisture from the soil in immediate contact with the roots. The soil moisture at contact points may be depleted to the permanent wilting percentage as determined by growing potted sunflower plants. If the rate of movement of water through the soil to the dried out soil is slower than the rate of extraction by the roots, we should have the phenomenon of an envelope of soil around the extracting root hairs in which the moisture content was at or near the permanent wilting percentage, while outside the envelope, at a few millimeters or some other distance from the root, the soil moisture might be well above the permanent wilting percentage and moving slowly toward the root.

In view of the fact that roots do not seem to occupy all parts of the soil mass (4) and in view of the slow rate of water movement through the soil, it seems likely that a condition of scattered volumes of soil whose soil moisture content may be at or closely approaching the permanent wilting percentage, interspersed through a body of soil whose moisture content is well above the wilting percentage, prevails when trees suffer while soil samples show available moisture in all parts of the root zone. Fig. 3 diagrammatically illustrates this idea. The cross section around the roots has been greatly enlarged and is not in proportion to the rest of the sketch, since the areas of soil around each root, here considered, are so small that it is impossible to check them by ordinary soil sampling means. In taking soil samples in the field the core of each whole foot in depth usually is taken, which would include soil both in and out of the dry soil envelopes. Therefore, in such cases, each "sample average" would always be greater than the wilting percentage as determined by growing potted sunflower plants, except when the concentration of tree roots per unit of rooting space equalled that of the roots of the potted sunflower plants, or when moisture moves so freely through the soil as rapidly to equalize zones of uneven moisture content. Conceivably a very occasional hole parallelling a series of extracting roots might show at all depths the permanent wilting percentage. This would not occur very often under conditions of sparse root population. Where as many as 11 locations per tree are sampled, the possibility of all locations reflecting the permanent wilting percentage at the time the tree first shows unmistakable signs of lack of readily available water would be extremely small.

This hypothesis is supported by data secured in 1934 by Aldrich and Work (3) who found that removal of 20% of the roots of pear trees in clay soil resulted in water deficit to the trees during warm summer weather.

SUMMARY

One group of workers believes that trees may suffer for lack of water while the moisture content of all material portions of the roots zone is still well above the permanent wilting percentage.

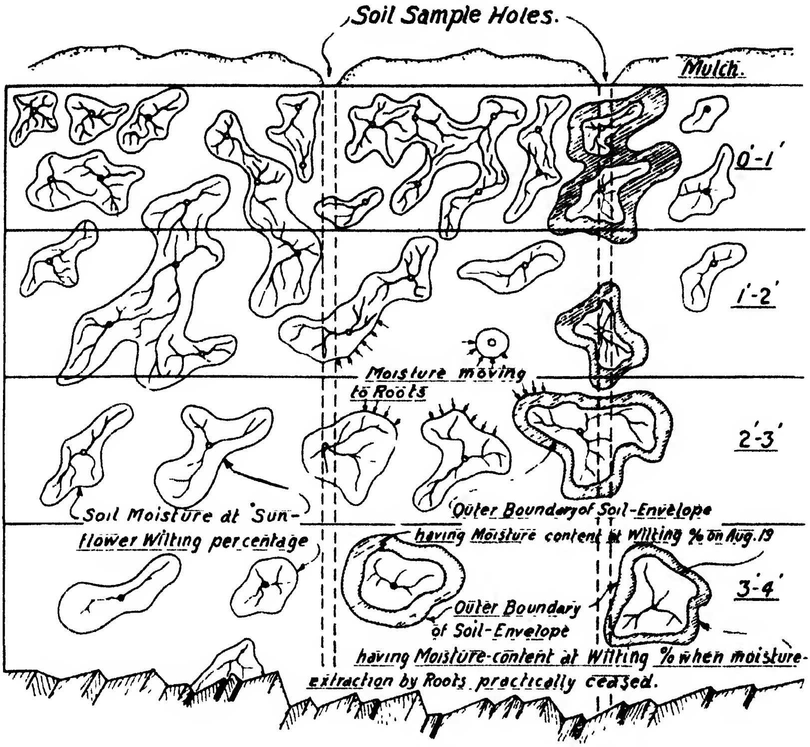

FIG. 3.—Hypothesis of soil moisture conditions in root zone of Klamath tree E4 from incipient to permanent wilting in 1931. (The cross section around the roots has been greatly enlarged and is not in proportion to the rest of the sketch, since the areas of soil around each root, here considered, are so small that it is impossible to check them by ordinary soil sampling means.)

A second group believes that soil moisture is as readily available near the permanent wilting percentage as it is near the field capacity.

A pear tree on Meyer clay adobe soil near Medford, Ore., was observed to wilt and partially defoliate while the average moisture content of each foot depth of soil and of almost all individual soil samples was well above the permanent wilting percentage.

When this tree showed serous suffering from water shortage, intensive soil moisture sampling showed that no material portion of the root zone was within 3.2% of the permanent wilting percentage.

Some days later the rate of extraction of soil moisture became markedly slower while the average moisture content of each foot depth of soil ranged from 1.7 to 4.2% above the permanent wilting percentage.

Still later, withdrawal of soil moisture at all depths, except for the first foot, ceased before the average content of any foot was depleted to the permanent wilting percentage.

The movement of water through the soil by capillary action was too slow to maintain a uniform condition in large masses of soil.

The roots do not seem to occupy the entire soil mass (4).

The following hypothesis appears to be valid: The soil moisture content of the soil in contact with the feeding roots may be at or near the permanent wilting percentage, while at the same time the moisture content at some distance, perhaps only a few millimeters away, may be much higher thus allowing the average content for an ordinary soil sample to be well above the wilting percentage at the time a tree shows serious distress for need of water.

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EFFECT OF NITROGENOUS FERTILIZERS, ORGANIC MATTER, SULFUR, AND COLLOIDAL SILICA ON THE AVAILABILITY OF PHOSPHORUS IN CALCAREOUS SOILS[1]

H. D. Chapman[2]

RECENT chemical studies (1)[3] have shown that, in general, the calcareous soils of southern California are well supplied in total phosphate and that this phosphate is readily soluble in very dilute acid (0.002 N sulfuric acid); however, it is difficultly available to plants. Results of a similar character have been secured by investigators in other western states (2,3,4). With soils well supplied with difficultly available but readily soluble phosphate, the question arises as to whether the availability of the phosphate can be measurably increased by physiologically acid nitrogen fertilizers, by sulfur, by organic matter, or by other materials such as colloidal silica. Conversely, it is desirable to know whether physiologically alkaline fertilizers decrease phosphate availability. Considerable importance is attached to this problem inasmuch as there are large areas of such soils in the semi-arid regions of the world, many of them being intensively cropped and heavily fertilized with both nitrogen- and phosphate-containing fertilizers.

Although much previous study has been devoted to the question of the effect of many materials on phosphate availability, particularly rock phosphate, insufficient work has been carried out with naturally calcareous soils to warrant general conclusions. It is unnecessary to review the extensive literature of this subject. It suffices to state that in the absence of calcium carbonate, physiologically acid fertilizers, organic matter, sulfur, and colloidal silica have often been shown to increase the availability of rock phosphate and, in some cases, that of the native soil phosphate.

The results of some preliminary studies with calcareous soils are reported in this paper.

EXPERIMENTAL

Three different calcareous soils containing variable amounts of phosphate and calcium carbonate were employed in a series of greenhouse pot tests, Sudan grass being used as the test crop. Each soil was thoroughly mixed, potted in 2-gallon earthenware jars, and differentially treated with equivalent amounts of various nitrogen fertilizers. Also included were various other treatments, such as sulfur, colloidal silica, and organic matter. A uniform treatment of calcium nitrate was given to all of the soils receiving the above non-nitrogenous constituents. The fertilizer materials (c.p. except for the sulfur, colloidal

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[3]Figures in parenthesis refer to "Literature Cited", p. 145.

silica, and organic matter) were thoroughly incorporated with the entire soil mass, the soluble ones being applied in solution. Full details as to the nature and rate of treatments are shown in the tables. The plants were watered throughout with distilled water. When approximately mature, the tops were harvested, dried, and weighed.

The variable yields of Sudan grass resulting from the different treatments are thought to be indicative, in a semi-quantitative way, of the effect of the added materials on phosphate availability. This belief is based on the following lines of evidence:

1. With the soils used (well supplied with total and dilute acid-soluble phosphate), Sudan grass grows very poorly when fertilized with calcium nitrate alone, whereas upon the addition of dicalcium phosphate along with calcium nitrate growth is markedly increased (Figs. 1, 2, and 3). This marked response to phosphate additions denotes then that where nitrogen only is added phosphorus becomes the most limiting factor for good plant growth; hence, any significant increase in growth over that produced by calcium nitrate alone is most logically, though perhaps not conclusively, interpreted as being due to a positive effect of the material added on the availability of the native soil phosphate.

2. The varying yields produced by a given material on the three different soils used in these experiments were in general agreement with theoretical expectation. One of the soils (Table 1) is low in carbonate and high in dilute acid-soluble phosphate; another is higher in carbonate and lower in phosphate; the third is intermediate in carbonate, but very much lower in phosphate. An increase in plant growth resulting from any positive effect of the applied material on phosphate availability should be greatest on the first soil, less on the second, and least on the third. In general, this was found to be true.

TABLE 1.—*Data on soils.*

Soil No.	Soil type	pH	Carbonate as $CaCO_3$, %	Total PO_4 in dry soil, p.p.m.	Water-soluble PO_4 in dry soil, p.p.m.	Acid soluble PO_4* in dry soil, p.p.m.
18758	Yolo clay loam	7.7	0.43	5,080	2.2	2,148
18604	Yolo clay loam	8.3	3.72	6,080	0.6	1,192
18543	Hanford sandy loam	8.2	1.15	2,040	0.2	138

*Determined by the Truog method.

Data showing the pH, carbonate content, and the total water-soluble, and acid-soluble phosphate of the three soils are presented in Table 1. Previous experiments had shown that these three soils are well supplied with potash; hence, none was added. As shown in the tables, the nitrogen was applied at a rate of 300 pounds per acre. Although somewhat heavy, such a rate is not out of line with commercial practice under intensive cropping. Moreover, being thoroughly incorporated with the entire mass of soil in the pots, its concentration was not as great as would result from smaller but more localized field applications.

Statistical treatment of the yield data has shown that differences of less than 10% are not significant.

EFFECT OF NITROGENOUS FERTILIZERS

The effects of equivalent amounts of different nitrogenous fertilizers on the growth and yields of Sudan grass are presented in Fig. 1 and Table 2, respectively.

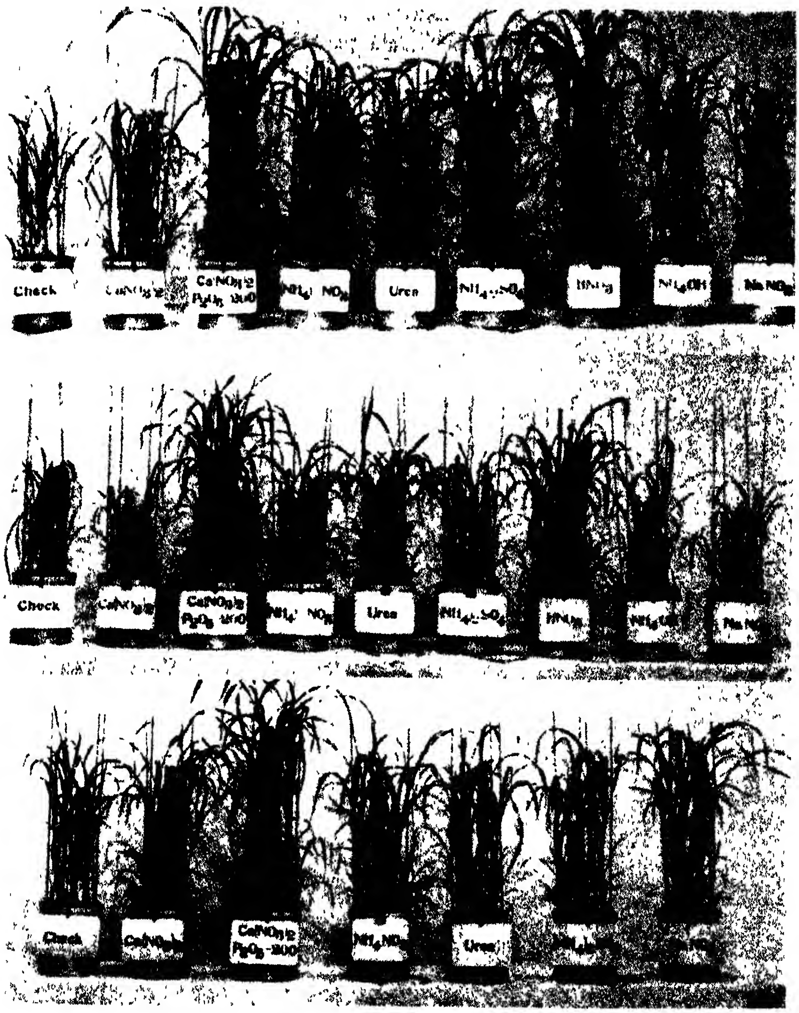

FIG. 1.—Effect of various nitrogenous fertilizers on the availibality of phosphorus in calcareous soils. *Top*, soil No. 18758; low carbonate, high phosphate. *Middle*, soil No. 18604; medium carbonate, medium phosphate. *Bottom*, soil No. 18543; low carbonate, low phosphate.

TABLE 2.—*Effect of various nitrogenous fertilizers on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604			Soil No. 18543		
		Yield			Yield			Yield		
Material	Rate per acre, pounds	Grams* per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams* per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams* per pot	Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	6.2	129.0	7.9	8.6	71.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	4.8	100.0	7.8	12.0	100.0	8.2
$CaH\ PO_4$	50 P_2O_5	11.7	101.0	7.4	11.5	239.0	7.9	9.9	82.0	8.3
$Ca(NO_3)_2$ } $CaH\ PO_4$ }	300 N } 50 P_2O_5 }	22.0	189.0	7.4	13.6	283.0	7.9	30.3	252.0	8.2
$Ca(NO_3)_2$ } $CaH\ PO_4$ }	300 N } 200 P_2O_5 }	35.3	304.0	7.6	16.7	336.0	7.8	47.4	392.0	8.1
$Ca(NO_3)_2$ } $CaH\ PO_4$ }	300 N } 600 P_2O_5 }	46.5	400.0	7.5	19.8	412.0	7.7	54.5	452.0	8.0
$NaNO_3$	300 N	12.3	106.0	7.3	7.1	148.0	8.0	14.7	122.0	8.4
$(NH_4)_2\ SO_4$†	300 N	20.0	172.0	7.4	—	—	—	—	—	—
$(NH_4)_2\ SO_4$‡	300 N	28.8	248.0	7.6	9.6	200.0	8.0	11.4	94.0	8.1
$NH_4\ NO_3$	300 N	18.4	159.0	7.7	8.1	168.0	8.1	11.7	97.0	8.2
Urea	300 N	16.1	139.0	7.5	12.0	250.0	7.8	11.4	94.0	8.2
$H\ NO_3$	300 N	42.4	365.0	7.6	28.2	578.0	7.9	34.5	286.0	8.1
NH_4OH	300 N	12.9	111.0§	8.0	8.1	168.0	7.7	27.3	218.0	8.3

*Dry matter at 60° C. Average of triplicate treatments.
†Applied in solution.
‡Applied as salt.
§Slight crop injury.

It will be noted that the yields resulting from applications of calcium nitrate alone were only slightly greater than the checks in two of the soils and somewhat less on the other soil. Previous work had shown that larger applications of calcium nitrate (400 pounds nitrogen per acre) slightly depressed plant growth on certain phosphate-deficient soils. This probably resulted from decreased phosphate solubility. Hence, the expression of the yields on the basis of calcium nitrate as 100 slightly exaggerates the effects of the other treatments. For example, the yields produced by the sodium nitrate, though relatively better than those secured with calcium nitrate, are thought to possess little or no significance as regards phosphate availability. The reduced yields with calcium nitrate as compared with those from sodium nitrate may possibly measure the extent to which the former has decreased phosphate availability in the different soils.

The greatest effect on growth, aside from that resulting from direct phosphate applications, was produced by nitric acid. Ammonium sulfate, ammonium nitrate, and urea produced significant increases over calcium nitrate on the two high phosphate soils, but were without effect on the low phosphate soil. Significant increases in growth were also obtained with ammonium hydroxide on two of the soils, but at a rate of 300 pounds per acre it was slightly toxic to the plants grown in soil No. 18758.

The increased growth resulting from nitric acid as contrasted with equivalent amounts of nitrogen in the other forms is noteworthy since the base-neutralizing capacity of 1 equivalent of nitrogen as nitric acid is the same as that resulting from the nitrification of ammonium nitrate, urea, and ammonium hydroxide, and only one-half that of ammonium sulfate. The difference is probably due in part to a mass-action effect; for in the nitrification of ammonium compounds only small amounts of acid are produced at any one moment, whereas the entire quantity of nitric acid would be effective immediately. This suggests the possibility that the rate of nitrification of ammonium compounds in soils may be important in determining the magnitude of the immediate effect of phosphate availability.

The results in general indicate that physiologically acid nitrogen fertilizers are capable of increasing the availability of phosphate in calcareous soils. Their effectiveness will be dependent upon the phosphate-calcium carbonate ratio of the soil, the nature of the materials used, and perhaps the rates at which they are nitrified in the soil. Obviously, rate and manner of application will also be important.

EFFECT OF SULFUR AND COLLOIDAL SILICA

The results obtained with sulfur and with colloidal silica alone and in combination with sulfur are presented in Fig. 2 and Table 3.

The most outstanding effect is that produced by sulfur: in soil No. 18758 sulfur applied at a rate of 4,000 pounds per acre gave a yield increase greater than that obtained from phosphate applied at a rate of 600 pounds of P_2O_5 per acre. The effect was also comparatively great on the other two soils.

Colloidal silica slightly increased the yields on two of the soils. The material used was anhydrous and granular (40-mesh and finer),

TABLE 3.—*Effect of sulfur and SiO_2 on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604*			Soil No. 18543*		
Material	Rate per acre, pounds	Yield: Grams† per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH	Yield: Grams† per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH	Yield: Grams† per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	4.6	143.0	8.1	3.1	129.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	3.2	100.0	8.0	2.4	100.0	8.1
$Ca(NO_3)_2$ + CaH_2PO_4	300 N + 50 P_2O_5	22.0	189.0	7.4	19.7	615.0	7.9	20.3	845.0	8.3
$Ca(NO_3)_2$ + CaH_2PO_4	300 N + 200 P_2O_5	35.3	304.0	7.6	23.3	726.0	7.8	31.7	1,320.0	8.1
$Ca(NO_3)_2$ + CaH_2PO_4	300 N + 600 P_2O_5	46.5	400.0	7.5	28.7	895.0	7.7	36.6	1,520.0	8.0
$Ca(NO_3)_2$ + Sulfur	300 N + 4,000 S	48.7	419.0	5.6	9.3	290.0	7.3	7.6	316.0	7.4
$Ca(NO_3)_2$ + Sulfur + Colloidal SiO_2	300 N + 4,000 S + 5,900 SiO_2	52.2	448.0	5.8	—	—	—	—	—	—
$Ca(NO_3)_2$ + SiO_2	300 N + 5,900 SiO_2	16.9	145.0	7.5	3.3	103.0	8.0	3.5	146.0	8.0
$Ca(NO_3)_2$ + Na_2SiO_3	300 N + 950 SiO_2	11.6	100.0	8.0	2.2	69.0	7.9	2.3	96.0	8.2

*Three previous crops of Sudan grass were grown on these soils, the previous pot treatment having been similar but at different rates. The old roots were screened out, the soil leached with distilled water, and subsequently retreated with the materials indicated.

†Dry matter at 60° C. Average of triplicate treatments.

being a commercial product. Although this material exhibited certain colloidal properties, such as heat of wetting and dye adsorption, it is possible that a hydrated form might have had a more pronounced effect. Of possible significance is the yield increase attending its use in combination with sulfur on soil No. 18758.

Sodium silicate was slightly depressive in two soils and without effect on the other. This result is of interest since Scarseth (5) has

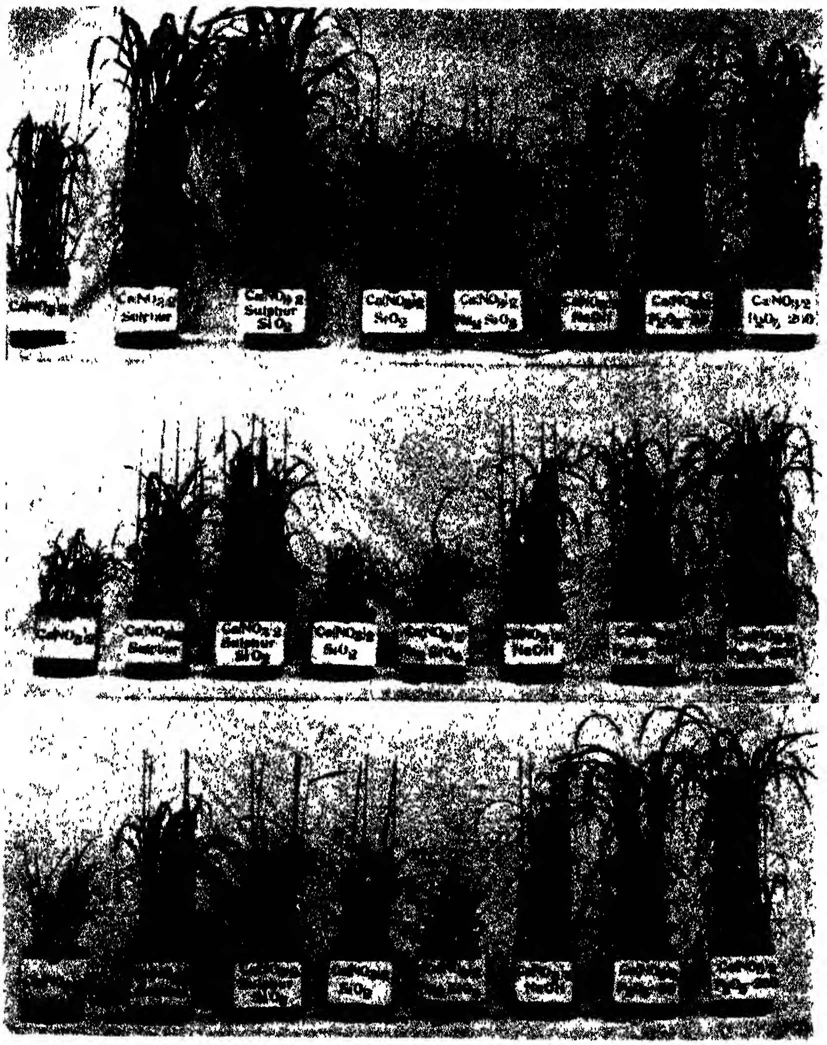

FIG. 2.—Effect of sulfur, colloidal silica, and sodium silicate on the availability of phosphorous in calcareous soils. *Top*, soil No. 18758; low carbonate, high phosphate. *Middle*, soil No. 18604; medium carbonate, medium phosphate. *Bottom*, soil No. 18543; low carbonate, low phosphate.

recently shown that sodium silicate will increase phosphate solubility and availability in certain soils, presumably by virtue of anion exchange. It may be that in calcareous soils no phosphorus is held in exchangeable form.

EFFECT OF ORGANIC MATTER

The results obtained with organic matter are shown in Table 4 and Fig. 3. With filtered paper and nitrogen (each mixed separately with the soil), growth was markedly depressed. Former experiments had given similar results. When phosphate was added, however, the yield obtained was greater than that from the same amount of phosphate without filter paper. It appears that the depressive effect of filter paper when used without phosphate was due to the competition for soluble phosphate between the cellulose-decomposing organisms and the Sudan grass. The increased growth resulting from the filter paper and phosphate combination over the phosphate alone is indicative of a favorable influence on phosphate solubility occasioned, presumably, by decomposition products of the cellulose.

With ground barley straw substantial growth increases were secured. However, it is certain that a part, at least, of these increases resulted from the phosphate of the straw. Nearly two-thirds of the total phosphate of the barley appeared in a water extract as inorganic phosphate, and some of this was, of course, immediately available. With soil No. 18758 the application of phosphate in combination with barley straw produced no better effect than phosphate alone, while with soil No. 18604 the result was somewhat better. There is no definite evidence, therefore, of a beneficial influence from the barley straw other than that which can be ascribed to its own phosphorus content

Although entirely preliminary in nature, the work with the organic materials indicates the importance of the phosphorus-carbon ratio and the possibility that with a favorable ratio, phosphate availability may be increased through the solvent action of the products of decomposition. Much more work is needed to determine the relative importance of the various factors that come into play when organic materials are applied to soils.

DISCUSSION

Under the conditions of these tests physiologically acid nitrogen fertilizers and sulfur increased the availability of phosphate in calcareous soils. The practical application of these results, however, must await further investigation. Under field conditions, the zone in which the materials are incorporated in relation to that of the absorbing roots of crops will, of course, be important. Since ammonium ions are fixed by the base-exchange components of soils, it is improbable that there will be much movement downward of this form of nitrogen; hence, its solvent effect will be limited largely to the zone of incorporation. The effect of sulfur and organic matter will likewise be confined largely to surface layers unless special methods of deep incorporation are employed.

Under irrigation agriculture, the composition of the irrigation water will be a factor of some consequence. Most waters contain more or

TABLE 4.—*Effect of filter paper and barley straw on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604*			Soil No. 18543		
Material	Rate per acre, pounds	Yield: Grams† per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH	Yield: Grams† per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH	Yield: Grams† per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	4.6	143.0	8.1	3.1	129.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	3.2	100.0	8.0	2.4	100.0	8.1
$Ca(NO_3)_2$, $CaH PO_4$	300 N, 50 P_2O_5	22.0	189.0	7.4	19.7	615.0	7.9	20.3	845.0	8.2
$Ca(NO_3)_2$, $CaH PO_4$	300 N, 200 P_2O_5	35.3	304.0	7.6	23.3	726.0	7.8	31.7	1,320.0	8.1
$Ca(NO_3)_2$, $CaH PO_4$	300 N, 600 P_2O_5	46.5	400.0	7.5	28 7	895.0	7.7	36.6	1,520.0	8.0
$Ca(NO_3)_2$, Ground filter paper	300 N, 1910 carbon	—	—	—	—	—	—	1.4	58.0	8.0
$Ca(NO_3)_2$, Ground filter paper, $CaH PO_4$	300 N, 1910 carbon, 200 P_2O_5	—	—	—	—	—	—	43.4	1,810.0	8.2
$Ca(NO_3)_2$, Ground barley straw	300 N, 1,950 carbon, 79.0 P_2O_5	23.0	198.0	7.4	18.1	565.0	7.9	—	—	—
$Ca(NO_3)_2$, Ground barley straw, $CaH PO_4$	300 N, 1,950 carbon, 79.0 P_2O_5, 200 P_2O_5	34.6	298.0	7.4	27.0	844.0	7.6	—	—	—

*Three previous crops of Sudan grass were grown in these soils, previous pot treatment having been similar but at different rates. The old roots were screened out, the soil leached with distilled water, and subsequently retreated with the materials indicated.

†Dry matter at 60° C. Average of triplicate treatments.

less calcium, bicarbonate, and hydroxyl ions; consequently, they will counteract to some extent the solubilizing effect of acid-forming materials.

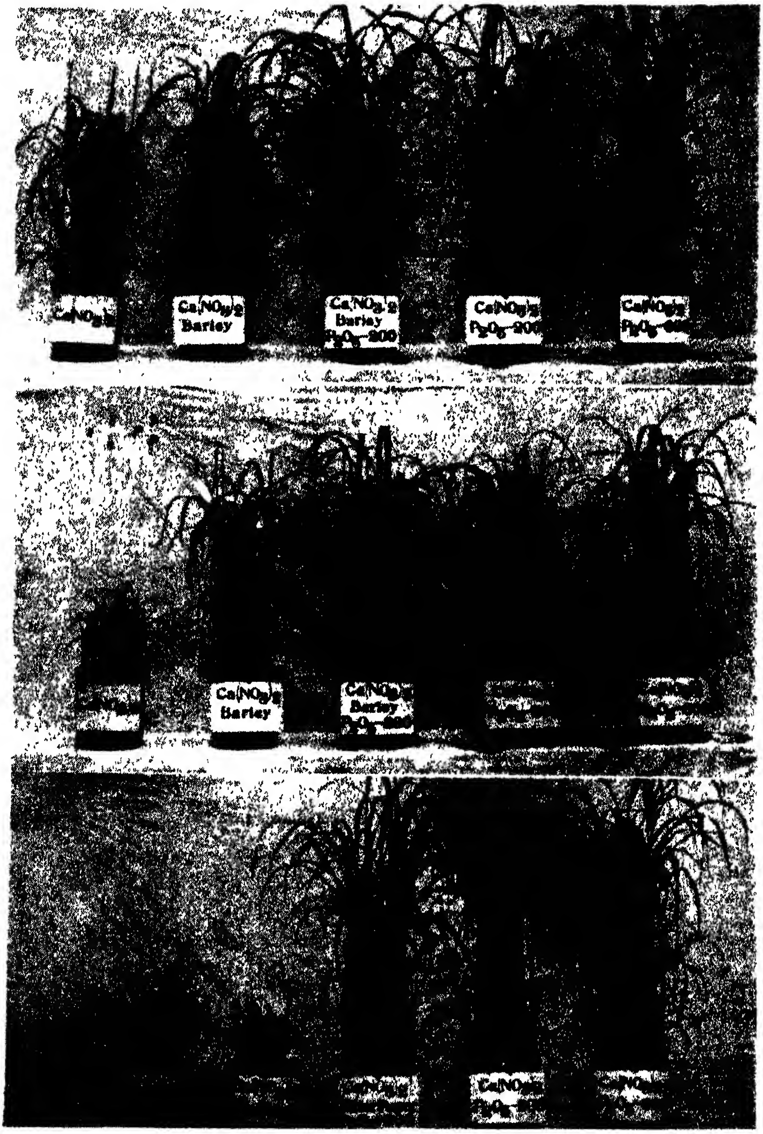

FIG. 3.—Effect of barley straw and filter paper on the availability of phosphorus in calcareous soils. *Top*, soil No. 18758; low carbonate, high phosphate. *Middle*, soil No. 18604; medium CaCo$_3$, medium phosphate. *Bottom*, soil No. 18543; low carbonate, low phosphate.

The efficacy of any given material will obviously be influenced by the relative amounts of carbonate and phosphate in the soil. The soils studied were relatively low in calcium carbonate (3.7% or less) and moderately well supplied with phosphate. Many semi-arid soils contain much greater quantities of carbonate; hence, further work is needed to determine more definitely the influence of the carbonate-phosphate ratio. Fineness of division of the carbonate and the nature of the dominant phosphate compounds may also be important.

SUMMARY

Pot culture studies with Sudan grass to determine the effect of various nitrogenous fertilizers, sulfur, colloidal silica, and organic matter on the availability of phosphorus in three calcareous soils have shown the following:

1. Physiologically acid nitrogen fertilizers increased phosphate availability, the magnitude of the effect being related to the carbonate-phosphate ratio of the soil and the nature of the materials used.
2. Sulfur markedly increased phosphate availability in all of the soils studied, being particularly effective on a soil low in carbonate and high in phosphate.
3. Colloidal silica slightly increased phosphate availability.
4. Sodium silicate was without effect.
5. Filter paper added without phosphate applications depressed the yields of Sudan grass presumably as a result of the competition for phosphate between cellulose-decomposing organisms and the plants. When filter paper was supplemented by phosphate, the yields were greater than those obtained with phosphate alone, indicating that carbon dioxide or other decomposition products of the filter paper increased phosphate availability. On the other hand, no effects were obtained from ground barley straw other than those which might be ascribed to the phosphorus it supplied.

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THE FIXATION OF POTASH BY MUCK SOILS[1]

G. H. Enfield and S. D. Conner[2]

Muck soils as a rule are naturally deficient in potash or soon become so when cropped. This makes it necessary to apply potash fertilizers to maintain high crop yields. The amount, kind, and placement of the fertilizer not only depends upon the crop needs but also upon the soil characteristics. The affinity of certain soils for soluble phosphate has prompted some investigators (2, 15)[3] to recommend that it should be applied in a restricted area near the seed. Other investigators (5) have found that under intensive cropping conditions a sufficient amount of potash cannot be safely placed near the seed without some danger of reducing germination. Since fixation can be either beneficial or detrimental, the most desirable method of applying fertilizer depends partially on the degree to which it is fixed.

In a study on low moor soils, Krugel, Dreyspring, and Heinerich (6) found that, in certain cases, the absorptive fixation of potash salts caused by the action of humic substances was very great. It was so great that 267 pounds of K_2O per acre were insufficient to produce good crops and it was necessary to make an additional application of one-half the original quantity before barley would grow normally. Such evidence would indicate that muck soils of this country might possess high potash-fixing ability.

Volk (16), in his work on several mineral soils, found that by using single extractions with dilute salt solutions or even weak acids, it was impossible to remove all of the potassium he had applied, if the soils had been either dried or dried and heated after the addition of potash salts. He concluded that a portion of the potash was converted into muscovite which is only slowly soluble.

Likewise, Frear and Erb (4) found that a portion of the potash applied to Hagerstown silt loam on the Pennsylvania State College fertility field was fixed in a form that could not be leached out in a short time nor cropped out in a season.

McCool (8) claims that mucks with the greatest amount of mineral matter show the greatest fixation. Others (3, 7, 9, 10) think that the acidity may be an important factor affecting the fixation of potash.

Fixation studies have usually been made by chemical methods. The assumption is then made that such a chemical measure of potash fixation is a good indication of the amount of potash which is unavailable to plants.

The study reported here was made in the greenhouse by growing four crops in pots fertilized with potassium chloride by two methods, *viz.*, in a layer and mixed with all of the soil. The difference in the

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 14, 1935.

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[3]Figures in parenthesis refer to "Literature Cited", p. 155.

amount of potash removed by the plants from the soil fertilized by the two methods was determined. Neubauer studies were made to determine the amount of available potash in the mucks before and after growing the four crops. The effect of these two levels of fertility was also noted on the seedling's ability to remove small amounts of additional potash with and without lime.

DESCRIPTION OF SOILS

Soil No. 10 is a loose, brown, fibrous muck which had been overdrained but well fertilized for two seasons. Neither crop was harvested due to crop failure.

Soil No. 20 is a black, well-decomposed muck from a field on which potatoes and corn had been grown for a long time. High yields had been maintained by large applications of fertilizer high in potash.

Soil No. 30 is a black muck similar to No. 20 with the exception that it was from the untreated plat at the Pinney-Purdue Muck Experiment Field near Wanatah The yields from this plat indicate that it was in a very low state of fertility.

Soil No 40 is a black, well-decomposed calcareous muck. Although the particular part of the field from which this sample was taken had received large applications of fertilizer and careful management, it had failed to produce profitable yields of onions. Later it was found that the addition of both copper and manganese was needed before good crops could be grown on this soil.

Soil No 50 is a brown, peaty muck, very acid and high in ash content. A heavy application of clay had been applied the year before the sample was procured.

A brief chemical description of each soil is reported in Table 1.

METHODS AND PLAN OF EXPERIMENT

The moisture-holding capacity of the mucks was determined in tubes having perforated bottoms by saturating air-dry samples with distilled water. The saturated mucks were allowed to drain for about 5 minutes, then the tubes were wiped dry and weighed. The moisture-holding capacity recorded in Table 1 is the amount of water remaining in 100 grams of moisture-free muck.

The exchangeable bases were determined by the method described by Schollenberger and Dreibelbis (12) with the exception that 10 grams of muck were leached with 350 ml. neutral ammonium acetate instead of the usual quantity. The results were calculated to milli-equivalents of the bases per 100 grams of moisture-free muck.

The elements soluble in 0.2 normal nitric acid were determined by digesting 1 part air-dry muck with 10 parts of the acid at room temperature for 24 hours.

The Neubauer results were determined by the method used by Thornton (14) except that 33 1/3 grams of muck instead of 100 were used. The moisture was maintained at 50% of the soil's water-holding capacity.

All of the potassium determinations on the soils were made by the A.O.A.C. chloroplatinate method. The potash in the plant ash was determined by the perchloric acid method described by Scott (13), except that a Whatman No. 42 filter paper was used instead of asbestos. After the paper had been dried free of alcohol it was placed in a funnel. The potassium perchlorate washed through with hot water into a tared dish, evaporated to dryness on a steam bath, and weighed after 1 1/2 hours of ignition at 300° C. This is a modification of the method by Baxter and Rupert (1), which is very rapid and gives concordant results.

TABLE 1.—*Chemical description of the muck soils used in the experiment on moisture-free basis.*

Soil No.	Loss on ignition %	Insoluble matter in 1.115 Sp. Gr. HCl %	Moisture-holding capacity, grams H_2O per 100 grams of muck	Milligram-equivalents of exchangeable elements per 100 grams of moisture-free soil				Soluble in N/5 HNO_3				Neubauer, mg. K_2O*	K availability†	P availability†	pH
				Total bases	H	Ca	K	P_2O_5 %	CaO %	Mn_3O_4 %	K_2O %				
10	86	6.7	571	126	33	75	4.0	0.03	2.7	0.025	0.08	30	H+	M—	5.2
20	76	13.5	250	140	9	106	2.4	0.06	3.2	0.015	0.09	35	H++	H++	5.9
30	69	19.2	195	113	26	67	0.7	0.014	2.7	0.028	0.014	6	O	L	5.3
40	76	8.25	299	147	0	143	1.4	0.035	5.2	0.017	0.035	15	M	H++	8.0
50	50	44.0	253	71	30	32	0.8	0 04	1.0	0.013	0.03	11	L	L—	4.5

*Neubauer results are based on 33⅓ grams of moisture-free muck
†Determined by method described in Purdue Univ Circ 204. H = high, M = medium, L = low.

In the early fall of 1932 each of the previously described mucks was brought to the greenhouse, allowed to dry partially, and then thoroughly mixed. Six 6-gallon earthenware jars were filled to within about 2 inches of the top with each soil. The great variation in weight of the different mucks made it impractical to use the same weight of muck in all pots; however, the weight of each soil was the same in each of the six pots containing that soil.

All pots were fertilized with 4 grams of ammonium nitrate and 6 grams of mono-calcium phosphate mixed uniformly with the soil. Two of the pots of each muck so treated were designated as treatment 1; two, designated as treatment 2, were fertilized in addition with 4 grams of potassium chloride mixed completely with all the soil; while the remaining two pots, designated as treatment 3, were treated with the same amount of potassium chloride as in treatment 2 except that it was applied in a layer 3 inches below the surface. The potash treatments were equivalent to 320 pounds KCl per acre 6 inches. Later it was found necessary to add more nitrates, therefore 3 grams of calcium nitrate were added to each of the pots with soil No. 50 and 1½ grams to each of the remaining pots. Distilled water was added to all of the pots to 80% of the moisture-holding capacity, which is considered to be ideal by Tacke (6). Later this amount was cut down to 50% because the muck was thought to be too wet for good plant growth, although little growth difference was noticed.

RESULTS

Barley was planted in December and harvested in May. The average air-dried yield and potash content of plants per pot is recorded in Table 2.

TABLE 2.—*Effect of potassium chloride on growth and potassium content of barley.*

Soil No.	Treatment		Average dry weight per pot, grams	K_2O, dry weight basis, %	K_2O removed per pot, grams	K_2O added, grams	Average loss of K_2O per pot, grams	Loss or gain of K_2O per pot due to treatment, grams
	No.	Location						
10	1	Without potash	129.5	2.18	2.8	—	—2.8	—
	2	Potash mixed	149.0	3.83	5.7	2.5	—3.2	—0.4
	3	Potash in a layer	148.5	3.35	4.8	2.5	—2.3	+0.5
20	1	Without potash	161.5	2.79	4.5	—	—4.5	—
	2	Potash mixed	174.5	4.18	7.3	2.5	—4.8	—0.3
	3	Potash in a layer	162.5	3.18	6.2	2.5	—3.7	+0.8
30	1	Without potash	77.5	1.18	0.9	—	—0.9	—
	2	Potash mixed	137.0	2.41	3.3	2.5	—0.8	+0.1
	3	Potash in a layer	140.0	2.65	3.7	2.5	—1.2	—0.3
40	1	Without potash	56.0	2.65	1.5	—	—1.5	—
	2	Potash mixed	51.0	5.97	3.0	2.5	—0.5	+1.0
	3	Potash in a layer	56.0	5.03	2.8	2.5	—0.3	+1.2
50	1	Without potash	107.0	1.96	2.1	—	—2.1	—
	2	Potash mixed	122.0	3.38	4.1	2.5	—1.6	+0.5
	3	Potash in a layer	137.0	3.55	4.6	2.5	—2.1	+0.0

Since in all cases more potash was recovered than applied, it would seem that the soil was already well supplied with potash. Because of this high potash level a crop of tomatoes was grown to deplete the soils more thoroughly of their available potash. The plants were started in flats, later transferred to individual 4-inch pots, and were then heavily fertilized with nitrogen and phosphorus. When the tomato plants were about 8 inches high the soil was washed free from the roots and two plants were set into each of the 6-gallon pots in the experiment. Each plant was kept pruned to one terminal bud and all side branches thrown away.

The crop was harvested when the temperature of the greenhouse, due to summer heat, became unfavorable for good growth. The tomatoes were not analyzed, but a record of the yield of fruit was kept (Table 3). The tomato crop was of value largely in that it helped bring the available potash to a lower level.

TABLE 3.—*The effect of potassium chloride on the growth of tomatoes.*

Soil No.	Average fresh weight of fruit per pot, grams			Average increase due to potash	Increase for layer over mixed
	Without potash	With potash mixed with soil	With potash in a layer		
10	292	539	558	+257	+ 19
20	686	788	799	+107	+ 11
30	330	430	509	+140	+ 79
40	547	550	665	+ 60	+115
50	464	510	457	+ 20	− 53

In the fall of 1933 the soils were tested for water-soluble and exchangeable K_2O and all were found to be very deficient. It made little difference whether or not they had been treated previously with potash.

The dry mucks were moistened with distilled water and refertilized exactly as at the beginning of the experiment. Spinach, a cool season crop, was planted in early winter. This crop was found to be very sensitive to potash deficiency, as shown by yields in Table 4. The plants on soil No. 50 without potash died before those on treatments 2 or 3 reached maturity. The spinach was harvested at two dates. The best two plants out of each pot were harvested on March 15 and the remainder of the plants on March 27. All of the air-dry plants from each treatment were ground in a Wiley mill and analyzed for K_2O.

From Table 4 it may be noted that in all cases the most potassium was removed by the spinach where the KCl was applied in a layer. To find whether this was due to unfavorable fixation or merely because of the poor root system of spinach, a crop with a good root system was next tried. Since Sudan grass grows well in high temperatures and has a good root system, it was selected further to deplete the potash from the muck after the spinach crop had been harvested.

When the Sudan grass was about one-half grown, it could be seen that those plants fertilized in a layer were larger than those supplied with potash mixed with all the soil; although in both cases the potash

TABLE 4.—*Effect of potassium chloride on growth and potash content of spinach.*

Soil No.	Treatment No.	Treatment Location	Average fresh weight, grams	Average dry weight per pot, grams	K_2O, dry weight basis, %	K_2O removed per pot, grams	K_2O added, grams	Net loss or gain of K_2O per pot, grams	Residual K_2O over untreated
10	1	Without potash	2.25	0.57	1.22	0.07	—	−0.07	—
	2	Potash mixed	162.0	15.3	10.05	1.54	2.50	+0.96	+1.03
	3	Potash in a layer	244.0	20.0	9.82	1.84	2.50	+0.66	+0.73
20	1	Without potash	58.5	6.8	2.17	0.15	—	−0.15	—
	2	Potash mixed	241.0	21.3	7.95	1.68	2.50	+0.82	+0.97
	3	Potash in a layer	249.0	21.9	8.75	1.92	2.50	+0.58	+0.73
30	1	Without potash	2.5	0.52	1.73	0.09	—	−0.09	—
	2	Potash mixed	262.5	19.1	6.02	1.15	2.50	+1.35	+1.44
	3	Potash in a layer	265.0	25.0	7.65	1.91	2.50	+0.59	+0.68
40	1	Without potash	4.0	0.87	1.42	0.12	—	−0.12	—
	2	Potash mixed	121.5	10.3	9.54	0.98	2.50	+1.52	+1.64
	3	Potash in a layer	140.5	10.5	10.22	1.07	2.50	+1.43	+1.55
50	1	Without potash	—	—	—	—	—	—	—
	2	Potash mixed	271.0	21.3	8.49	1.81	2.50	+0.69	+0.69
	3	Potash in a layer	276.0	22.5	8.31	1.87	2.50	+0.63	—

greatly increased the growth. The average yield in grams and the potash content is shown in Table 5. The potash removed by Sudan grass, like that in spinach, was in all cases greater in treatment 3 than in treatment 2, indicating some unfavorable fixation.

TABLE 5.—*Effect of potassium chloride on the growth and potash content of Sudan grass and net loss or gain of potash per pot due to treatment.*

Soil No.	Treatment No.	Treatment Location	Average dry weight per pot, grams	K_2O, dry weight basis, %	K_2O removed per pot, grams	Net residual K_2O after spinach, grams	Residual K_2O over treatment 1 after Sudan grass, grams
	1	Without potash	49.0	0.58	0.28	—	—
10	2	Potash mixed	146.0	0.50	0.73	1.03	+0.58
	3	Potash in a layer	158.0	0.62	0.98	0.73	+0.03
	1	Without potash	98.0	0.58	0.57	—	—
20	2	Potash mixed	166.0	0.71	1.18	0.97	+0.36
	3	Potash in a layer	167.0	0.87	1.45	0.73	—0.13
	1	Without potash	88.0	0.46	0.40	—	—
30	2	Potash mixed	145.0	0.71	1.03	1.44	+0.81
	3	Potash in a layer	160.0	0.66	1.06	0.68	+0.02
	1	Without potash	28.0	0.90	0.25	—	—
40	2	Potash mixed	35.0	2.91	1.02	1.64	+0.93
	3	Potash in a layer	38.0	2.88	1.09	1.55	+0.71
	1	Without potash	66.0	0.62	0.41	—	—
50	2	Potash mixed	167.0	0.57	0.95	0.69	+0.15
	3	Potash in a layer	187.0	0.54	1.01	0.63	+0.03

The Neubauer (11) method is a means by which the amount of phosphorus and potassium available to plants in any given soil can be estimated. If one should estimate the amount present in any soil and then add a small quantity of potash in an available form, it should be recovered in addition to the amount supplied by the soil, provided that other soil factors are favorable and that the sum of the amount added and that already in the soil is not greater than the absorptive capacity of the plants.

Three sets of duplicate Neubauer tests were started on each soil. One set was run on each original soil without treatment; another with 25 mg of additional K_2O in the form of potassium chloride; and the third with 25 mg of K_2O plus 0.56 gram CaO.

Each muck mixed with 50 grams of sand was uniformly moistened and dried, then again moistened and air dried to give the potash a chance to react with the soil.

From the results of the previous pot tests, it might be expected that potash fixation would be greater in potash-deficient than in high potash mucks, therefore the second set of Neubauer tests was run on soils which had grown four successive crops without added potash. These mucks were all very much depleted of available potash, as shown in Table 6. It may be noted that the Neubauer potash is

lower in the cropped soils than in the original soil. The percentage of added potash recovered, however, is greater from the cropped than from the original soils, with the exception of soil No. 50 which is the one high in ash, indicating that the potash present in the uncropped soil approached the absorptive capacity of the rye seedlings and that some unfavorable fixation might have taken place in soil No. 50.

TABLE 6.—*Milligrams of K_2O extracted from the muck by Neubauer method before and after four greenhouse crops were removed.*

Soil No.	Untreated soil		Soil+25 mgms K_2O		Soil+25 mgms K_2O+ 1 gram $CaCO_3$		Mgms K_2O applied that were recovered			
							Without $CaCO_3$		With $CaCO_3$	
	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped	Cropped
10	29.6	3.3	49.7	24.5	50.0	27.9	20.1	21.2	20.4	24.6
20	34.5	3.2	52.3	23.8	51.6	26.2	17.8	20.6	17.1	23.0
30	6.0	5.6	27.2	26.8	26.1	27.0	21.2	21.2	20.1	21.4
40	15.2	5.1	35.0	28.4	35.0	27.3	19.8	22.3	19.8	22.3
50	10.6	4.8	28.6	18.0	30.5	24.2	18.0	13.2	19.8	19.4

In studies of phosphate fixation by soils, it has been found that the amount fixed depends partially upon the amount of soil within reactable distance of the soluble phosphate. Conditions should then be more favorable for fixation of potassium if it were applied by mixing it with the entire pot of soil than if applied in a layer a few inches below the surface.

Barley, the first greenhouse crop, removed 0.4 and 0.3 gram more K_2O, respectively, from soils Nos. 10 and 20 than could be accounted for by adding the amount of potash removed from the untreated soil and the amount supplied by the 4 grams of potassium chloride mixed with all the soil. However, this may be due to a stimulation of root growth in mucks treated with potash. It would also indicate that the barley on these soils was more able to extract a given quantity of potash if distributed through the entire pot than if it were confined to a restricted area below the seed.

The other three soils responded inversely to soils Nos. 10 and 20. Neubauer tests, the amount of K_2O soluble in 0.2 normal HNO_3, crop yields, and the Indiana rapid tests all indicate that soils Nos. 10 and 20 were very high in available K_2O. This implies that both of these soils were already supplied with soluble K_2O and any additional amount of soluble potassium would probably not be adversely fixed.

Barley removed more potash from the soil than was applied. Tomatoes, which followed, further depleted the available potash to a very low level.

Spinach, the first crop after the depleted mucks were refertilized, removed on the average 0.25 gram more K_2O from the pots fertil-

ized with potassium chloride placed in a layer than with it mixed with all of the soil. After the spinach, the potash content of the soils was greatest in pots with treatment 2, but the following crop, Sudan grass, failed to remove as much potash from this treatment as it did from treatment 3.

The roots of the Sudan grass were numerous and extensive. After the plants were harvested and the soil became dry, one could remove the entire mass of roots and soil from the pot in one lump. After cutting this lump into thin slices no difference could be detected nor any localization of roots found at the zone where the layer of potash had been applied. The Sudan grass was tested for available potash by the Indiana plant tissue test and found to be very low in potash. Since the root system of the crop was good and the plants were capable of removing more potash from the soil had it been available, it would indicate that there was some fixation of potash by the depleted soils where it was applied mixed with the entire pot.

Neubauer results show that there was as much as 2.3 mgms of K_2O difference between the five mucks after the removal of four greenhouse crops. Soil No. 20, which contained the largest amount of available K_2O before cropping, had become the lowest in available potash after the removal of the greenhouse crops.

The effect of lime was found to be greatest on the most acid soils and there was a tendency to remove more potash in the presence of lime than in its absence. If lime had caused any fixation of the potash, it was more than overcome by some other effect it had on the plant. The soil with the most mineral matter caused the greatest amount of fixation and inversely the one with the least inorganic matter caused the least fixation. The addition of lime to the muck which was already calcareous did not show any change.

Since on the average only 80.7% of the potassium applied in the Neubauer experiments was recovered, it would indicate that there was some fixation of potash by muck soils as measured by this method.

SUMMARY

1. Five mucks, widely different in reaction, composition, and previous treatment, were tested in pots for potash fixation by growing four crops with three different treatments, *viz.*, without potash, with potash mixed with the entire pot of soil, and with potash applied in a layer beneath the seed.

2. More potash was recovered and larger yields were procured from pots of potash-deficient mucks treated with potash in a layer than from those with the potash mixed with all the soil.

3. In the case of mucks well supplied with potash, larger yields and more potash were obtained from the pots treated with the potassium chloride mixed with all the soil than from those with potash applied in a layer.

4. Fixation of 25 mgms of applied potash per 33⅓ grams of muck was studied by the Neubauer method before and after four greenhouse crops were removed without the addition of any potash fertilizers.

5. Larger amounts of the applied potash were recovered by the Neubauer method from potash-deficient soils than from those well supplied.

6. In the Neubauer studies, lime did not cause any appreciable fixation of potash.

7. On the very acid and potash-deficient mucks more potash was removed by the plants in the presence of additional lime than without the addition of lime.

8. There was a close correlation between exchangeable potassium, Neubauer results, and the response of plants in pots to potash fertilization.

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A COMPARISON OF WINTER LEGUME GREEN MANURE AND NITRATE OF SODA FOR FERTILIZING COTTON[1]

G. A. HALE[2]

IN recent years, farmers in the southeastern part of the United States have been increasing their acreage in vetches, Austrian peas, crimson clover, and other winter-growing legumes for use as green manure in fertilizing cotton and other spring-planted crops. This part of the cotton belt uses more commercial fertilizers than any other area in the United States, especially nitrogenous fertilizers. The experiment reported here was conducted to compare the value of vetch and Austrian peas with nitrate of soda for fertilizing cotton where cotton is grown continuously on the same land as is the custom on many cotton farms.

MATERIALS AND METHODS

Hairy vetch was planted on the winter legume plats during 1927 to 1931 and Austrian winter peas from 1931 to 1935, inclusive. The winter legume seeds were sown about the middle of October and a good growth, at least 1 ton of air-dry material per acre, was turned under 2 weeks before applying the fertilizers and planting the cotton the latter part of April each spring.

All the plats were fertilized with 600 pounds per acre of 16% superphosphate in the fall of 1927 when the experiment was started Beginning in the spring of 1928, an annual application of 600 pounds per acre of superphosphate and 64 pounds per acre of muriate of potash was made when the cotton was planted. The nitrate of soda was applied with the other materials and bedded on at planting time. The experiment was conducted on a rather poor phase of Cecil sandy loam soil which is typical of a large area of the Piedmont Soil Province

Seven series of systematically replicated six-row plats 90 feet long were used for each treatment. Only the four inside plat rows, or 1/34.6 acre, was harvested for yields. The total numbers of plants and hills were counted on the inside rows at picking time.

EXPERIMENTAL RESULTS

The 8-year average yield results in Table 1 show that vetch or Austrian peas turned under produced 93 more pounds of seed cotton per acre than 100 pounds of nitrate of soda per acre. The average yields of the green manure plats were better than those of the plats receiving 100 pounds of nitrate of soda, but not as good as those receiving 200 pounds of nitrate of soda. The green manure plats outyielded the 100-pound nitrate of soda plats every year except one.

Nitrate of soda used at the rate of 200 pounds per acre gave an acre yield increase of 110 pounds of seed cotton over the green manure treatment for the 8-year period, but approximately two-thirds of this

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TABLE 1.—*Pounds of seed cotton per acre produced on winter legume green manure and nitrate of soda treatments at the Georgia Experiment Station, 1928–35.*

Acre treatment*	Pounds of seed cotton per acre								
	1928	1929	1930	1931	1932	1933	1934	1935	8-yr. average
100 pounds nitrate of soda	844	858	897	1,072	896	924	1,145	969	951
200 pounds nitrate of soda	1,129	1,000	997	1,065	941	955	1,872	1,270	1,154
Green manure	1,057	786	1,009	1,133	936	1,085	1,160	1,187	1,044
Green manure and 100 pounds nitrate of soda	1,145	879	1,022	1,247	978	1,077	1,538	1,300	1,148
Green manure and 200 pounds nitrate of soda	1,057	897	915	1,172	882	971	1,638	1,303	1,104

*All treatments received 600 pounds superphosphate and 64 pounds muriate of potash.

increase resulted from the 1934 yield when the commercial nitrogen made an unusually good showing. The 6-year (1928–33 inclusive) results show no significant difference in the value of the two treatments

Supplementing the green manure with 100 pounds of nitrate of soda produced an increase in yield of 104 pounds of seed cotton per acre over green manure alone. Increasing the nitrogen to 200 pounds of nitrate of soda per acre decreased the yield, probably due to too rank a growth of the cotton, and reduced stands.

There appears to be no marked difference in the cumulative effect of the two treatments, as measured by the difference between the average yields of the first and last 2-year periods of the experiment.

A comparison of the stands as measured by both the number of plants and hills at picking time, as given in Table 2, shows no significant differences between the stands on the treatments except where both green manure and the heavier application of nitrate of soda resulted in fewer plants and hills than the other plats.

SUMMARY AND CONCLUSIONS

An 8-year field experiment was conducted on Cecil sandy loam soil at the Georgia Experiment Station in which winter legume green manure, nitrate of soda, and a combination of green manure and nitrate of soda were compared for fertilizing cotton.

Hairy vetch and Austrian pea green manure turned under 2 weeks before planting cotton produced slightly larger cotton yields than 100 pounds per acre of nitrate of soda applied when the cotton was planted.

Treatments comparing 200 pounds per acre of nitrate of soda and a winter legume green manure crop for fertilizing cotton showed an 8-year average difference of 110 pounds seed cotton per acre in favor of the commercial nitrate.

TABLE 2.—*Number of plants and hills per acre at picking time on green manure and nitrate of soda treatments, 1929–35.*

Acre treatment*	1929		1930		1931		1932		1933		1934		1935		7-yr. Av.	
	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre
100 pounds nitrate soda...	12,283	9,233	17,611	7,801	17,231	9,116	17,854	10,860	17,715	10,652	22,871	11,631	22,687	10,905	18,322	10,028
200 pounds nitrate soda....	16,919	11,292	14,843	6,621	14,567	8,057	15,120	10,091	16,020	10,299	21,763	11,119	23,867	11,136	17,586	9,802
Green manure...	15,639	9,780	17,231	8,178	15,605	8,628	17,508	10.939	19,030	11,164	20,656	11,154	14,404	8,932	17,153	9,825
Green manure... and 100 pounds nitrate soda....	14,878	9,815	16,349	7,540	13,667	7,912	15,449	10,177	17,248	10,460	20,587	11,194	13,785	8,564	15,995	9,380
Green manure... and 200 pounds nitrate soda....	14,342	9,614	12,975	6,474	11,712	7,189	14,411	9,561	15,362	9,811	20,241	11,012	14,826	9,050	14,838	8,959

*All treatments received 600 pounds superphosphate and 64 pounds muriate of potash.

Supplementing the green manure with 100 and 200 pounds of nitrate of soda per acre increased yields over green manure alone as cotton fertilizer.

Stands, as shown by both the total number of plants and hills per acre at picking, were slightly better on the green manure and nitrate of soda alone treatments than on the other treatments where both fertilizers were used.

NOTES

EFFECT OF DIFFERENT VARIETIES OF SORGHUM ON BIOLOGY OF THE CHINCH BUG

DURING the last several years the effects of chinch bugs (*Blissus leucopterus* Say) feeding on different sorghum and corn varieties studied at the U. S. Dry Land Field Station, Lawton, Okla., in cooperation with the Kansas Agricultural Experiment Station, have shown that the milos are very susceptible to chinch bug injury, that the feteritas are somewhat less susceptible, and that the kafirs and sorgos in general are rather resistant. In 1935, experiments were planned in cooperation with the Oklahoma Agricultural Experiment Station to study the effect of different varieties of sorghum on the biology of the chinch bug. Representative varieties of the above groups were selected for this study. The highly susceptible Dwarf Yellow milo was chosen as a typical variety of the milo group. Common feterita, which is slightly less susceptible than Dwarf Yellow milo under field conditions, represented the feterita group. Blackhull kafir was used as the typical kafir variety. Atlas sorgo, a highly resistant variety, was selected as a representative of the sorgo group.

Seedling plants of Atlas sorgo and Dwarf Yellow milo were used in studies to determine the effect of the host plant on the oviposition of overwintered females and also on the rate of development of first-generation nymphs. Overwintered adults were collected from a field of barley and placed in cages with these varieties for food Individual oviposition records were kept for all females. These females had probably laid some eggs in the field. During the remainder of the life period of these bugs, 12 females feeding exclusively on Atlas sorgo laid a total of 51 eggs, while 14 females feeding exclusively on Dwarf Yellow milo deposited 1,027 eggs, the averages being 4.3 and 73.4 eggs per female, respectively. The females feeding on Atlas plants lived an average of 8.5 days, while the longevity of females feeding on Dwarf Yellow milo plants averaged 23 days.

Complete records were kept of eggs laid by first-generation females on Dwarf Yellow milo, Blackhull kafir, Atlas sorgo, and common feterita. Ten pairs of adult bugs were tested on each of these four varieties. The 10 females on Dwarf Yellow milo laid 1,179 eggs, and their average length of life was 40 days. Eight females of the 10 feeding on Blackhull kafir deposited 219 eggs, and their average longevity was 29 days. Of the 10 females feeding on Atlas sorgo, only 4 laid eggs, a total of 9 being deposited. Fifteen days was the average length of life of the 10 females feeding on Atlas seedlings. No eggs were laid by the 10 females feeding on feterita, which indicated unsuitability for ov position in the seedling stage, although it is a susceptible variety under field conditions. Results are available which show that this variety develops considerable susceptibility as the plants become older.

Data have also been obtained which prove that chinch bugs reared on a susceptible variety can pass through their immature stages in much less time than those which are fed on a resistant variety. The average duration of the immature stages was 35.3 days when fed on

Dwarf Yellow milo and 45 days when fed on Atlas sorgo. The mortality of nymphs, after the first instar, when reared on Dwarf Yellow milo was 8% as compared with 84% when Atlas sorgo was the food plant. The average body length of adults reared on Dwarf Yellow milo was nearly 0.5 millimeter greater than that of those reared on Atlas sorgo.

Other experiments indicate that chinch bugs have the ability to to select plants of a susceptible variety for feeding in preference to those of a resistant variety when the plants of both varieties are placed adjacent to one another. Data have likewise been obtained in the laboratory which show that chinch bugs will kill plants of a susceptible variety in much less time than those of a resistant variety. The same number of bugs were confined on the different varieties tested under identical conditions in regard to age of plant, time of exposure, and, so far as known, all other conditions.—REYNOLD G. DAHMS and RALPH O. SNELLING, *U. S. Dept. of Agriculture, Lawton, Okla.*, and F. A. FENTON, *Oklahoma A. & M. College, Stillwater, Okla.*

A CONVENIENT LABEL STAKE FOR NURSERY PLATS

A METAL stake and label holder, shown in Fig. 1 designed at the United States Dry Land Station, Lawton, Okla., in 1933 has been sufficiently satisfactory to seem to merit a brief description.

The stake is made from 3/16-inch mild steel rod, cut in 2-foot lengths. An eye is turned on one end of the rod for attaching the label holder. The stake is bent just below the label holder, thereby placing the label at a convenient angle to read with the stake in a vertical position.

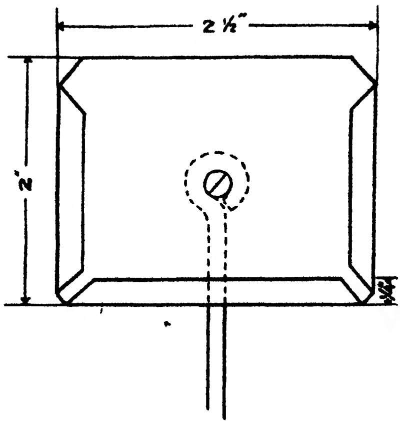

FIG. 1.—Diagram of a metal nursery stake and label holder.

The label holder is similar to that described by Swanson[1], but for attachment to a wooden stake. It is made from No. 28 gauge galvanized iron and is 2½ inches wide and 2 inches high. An ordinary manila tag, 2 3/8 by 4 3/4 inches, will make two labels for this holder. Manila tag board can be obtained in large sheets. The guides, about 3/16 to 1/4 inch in width, extend about 1 3/4 inches from the bottom of the holder. The top is only slightly crimped, which holds the label in place and permits its insertion or removal with ease. The bottom is crimped in the same manner as the guides. The holder is attached to the metal stake with a 1/2-inch flat head stove bolt, with a washer next to the stake. The head of the stove bolt is partly countersunk

[1]SWANSON, A. F. A useful holder for plat stake labels. Jour. Amer. Soc. Agron., 22: 188–189. 1930.

in the label holder so as not to interfere with inserting or removing the label.

This stake with holder attached can be pushed into the ground when the soil is too dry and hard to permit driving a wooden stake. If a stake should be bent, it can be straightened easily. The portion of the rod that is in the soil may rust slightly but that helps hold the stake in place. The latter may be pulled up easily after a turn to break the contact with the soil. This stake will last much longer than a wooden stake, especially at Lawton, Okla., where termites cause damage, and it is lighter and less bulky. The cost of both stake and label holder is small.

The metal stake is very satisfactory for the use of permanent labels for trees, shrubs, and other perennials. For this purpose a zinc label is used instead of a manila tag. Permanent lettering may be made on the zinc with special commercial inks or with the following formula: Copper acetate (basic), 1 dram; ammonium chloride, 1 dram; lamp black, ½ dram; and water, 10 drams.—R. O. SNELLING, *Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Lawton, Okla.*

BOOK REVIEW

THE LAND, NOW AND TOMORROW

By R. G. Stapledon. London: Faber and Faber. Ltd. xvii + 336 pages, illus. 15/. 1935.

PROFESSOR Stapledon is Director of the Welsh Plant Breeding Station and of course is well known to all research workers with grasses and grass land. In this book he makes a plea for better utilization of the land and the preservation of this possession on which, he believes, the future of British civilization rests. On the basis of the best figures obtainable he believes that if the decline in arable land continues at the present rate "no more than two hundred years may see the farm lands of England reduced to one half" and in four hundred years there will be "little or no agricultural land in the proper meaning of the word in England".

Being a grass specialist, Professor Stapledon discusses the various types of grass land, pointing out how they can be made more productive and thus sustain a larger agricultural population. The costs and returns from the various proposed operations are carefully analyzed, but on a basis of refunding over a term of years. He then points out that farmers need capital to undertake such improvements, the large amount of labor that would be given employment, and appeals to the state to make the condition of agriculture its concern. The author argues, as has been argued in this country, that the state will suffer from the decline of agriculture and should assist in putting it on a prosperous basis. Contrary to what has been argued in the United States, however, he pleads for greater production.

There is much more to the book than the writer of this brief review has expressed. The book should be read by every American student of the land and of agricultural problems. (A. J. P.)

AGRONOMIC AFFAIRS

MEETING OF THE SOILS SECTION OF THE SOCIETY

ALL sub-sections of the Soils Section of the Society participated in a joint program with the American Soil Survey Association at Chicago on the afternoon of December 5, 1935. A business meeting of the Soils Section convened immediately after the close of the program.

In the absence of the Secretary, Dr. H. J. Harper, Dr. C. W. Lauritzen was asked to serve as secretary previous to the election of Dr. Clarence Dorman of Mississippi as secretary for 1936. Dr. William A. Albrecht of Missouri was elected Chairman of the Section.

A motion was passed endorsing the action of the business meeting, December 4, of soil scientists belonging to any of the three organizations (American Soil Survey Association, American Society of Agronomy, International Society of Soil Science) recommending: (1) That the A.S.S.A. and the Soils Section of the A.S.A. unite to form a single organization; and (2) that the new organization shall be called "The American Society of Soil Science".

A motion was passed stipulating that the two members who had served on the committee to formulate plans for the union of all soil scientists into one organization should serve on a committee to draft a constitution for the new organization. The two committeemen are Dr. Richard Bradfield and Professor C. F. Shaw. The proposed constitution will be published in the JOURNAL prior to the annual meeting next fall.

A motion was passed authorizing the appointment of two members to serve on a committee with two members of the A.S.S.A. (Professor Truog and Mr. Baldwin) to formulate an editorial policy for papers submitted for presentation on the program of the new Society. Chairman Albrecht appointed Professor C. E. Millar and Professor Richard Bradfield to represent the Soils Section on this committee.

It was voted to leave to the committee on constitution the decision as to whether Section VI of the new organization was to be designated as Conservation or Technology.

The following resolution presented by Dr. J. G. Hutton was adopted: That the American soil scientists recommend to Congress that there be $1,000,000 appropriated yearly for 10 years for soil survey work, this money to be allocated to those states that appropriate $10,000 per year for soil survey purposes.

During Friday, December 6, the various sub-sections conducted programs under the direction of the chairmen, as follows: Dr. H. W. Batchelor, Biology; Dr. L. B. Olmstead, Physics; and, due to the illness of Dr. R. H. Bray, Mr. G. N. Ruhnke of Ontario Agricultural College was asked to serve as Chairman of the Chemistry Sub-section in the morning, and Dr. F. C. Bauer of Illinois of the Fertility program in the afternoon.

Chairmen of the three sub-sections for 1936 were elected as follows: Soil Physics, Dr. L. D. Baver of Missouri; Soil Biology, Dr. J. K.

Wilson of New York; Soil Chemistry and Fertility, Dr. R. H. Bray of Illinois, since illness prevented his presiding over the program he had arranged this year.—CLARENCE DORMAN, *Secretary*.

NEWS ITEMS

R. H. MORRISH, extension specialist in charge of sugar beet projects at Michigan State College, has resigned to accept a position with the Soil Conservation Service at Zanesville, Ohio. His place will be taken by G. F. Wenner, who has been working on general extension projects.

DR. CARTER M. HARRISON, National Research Council Fellow, has been appointed research associate in farm crops at Michigan State College, where he will conduct pasture investigations.

STANLEY P. SWENSON has resigned from his position as Research Assistant in the Division of Agronomy and Plant Genetics, University of Minnesota, to become Associate Professor of Agronomy at the South Dakota State College.

DR. H. B. MANN, Agronomist in Soil Fertility at the North Carolina State College of Agriculture, has joined the staff of the American Potash Institute, Inc. He will serve as Assistant Manager of the Southern Territory of the Institute with headquarters in Atlanta, Ga.

DR. WILLIAM G. COLBY has been named research professor of agronomy at Massachusetts State College. Dr. Colby was formerly assistant agronomist with the Soil Conservation Service of the U. S. Dept. of Agriculture.

ERRATUM

ON page 863 in Volume 27 of this JOURNAL, in the article on "The Determination of the Forms of Inorganic Phosphorus in Soils" by R. Anderson Fisher and R. P. Thomas, in the section on "Methods of Procedure", the sentence beginning "The pH 2 solution consists of a 0.002 N sulfuric acid and 0.3% of potassium acid sulfate" should read simply, "The pH 2 solution consists of 0.3% of potassium acid sulfate." Also, on page 871 of the same article, formula 3 at the bottom of the page should read "3 pH 2 for 3 hours gives A+6B/11+C/2."

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REGIONAL LAND USE FOR THE HARD RED WINTER WHEAT BELT[1]

R. I. THROCKMORTON[2]

IN considering a land use program for the hard red winter wheat belt it should be recognized that this agricultural region is primarily adapted to an extensive type of farming. It is a region adapted to the use of power machinery and to a type of agriculture in which the individual farmer cultivates a large acreage, has a high total production of grain in favorable years with a relatively low yield per acre and a low unit production cost. These conditions lead to a speculative type of agriculture. In a region such as this, soil and water are the most important natural resources and land use adjustments should be those that will aid in conserving these natural resources as well as assist in stabilizing the agriculture of the region.

Stabilization of production is one of the great needs of the agriculture in this region. It is essential that the wide range between extremely high total production during favorable years and the extremely low total production during unfavorable years be narrowed materially. Total crop failures on millions of acres of land occur too frequently, especially in the western portion of the region. They occur much more frequently than would be the case if a more conservative type of agriculture were practiced. A major objective of a well-developed land use program should be to reduce the agricultural hazards of the region.

The program must take into consideration the natural adaptation of the heavier soils, consisting of silt loams and silty clay loams, for the production of wheat. It should also give consideration to the climatic conditions which make this region better adapted to the production of hard red winter wheat than to most other crops.

During the early development of the hard winter wheat region little or no thought was given to land use or to crop adaptation. Land was broken from the native sod and seeded to wheat at an amazingly rapid rate. The fever of exploitation ran high and many

[1]Contribution No. 256 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kansas. Presented as a part of a symposium on "Regional Land Use" at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935.

[2]Head of Department.

mal-adjustments came into existence. Land too rolling, too sandy, or located in regions too deficient in rainfall for successful wheat production was placed under cultivation. Farm units were organized in some sections too small for economical production under the type of agriculture that must be practiced considering the climatic and market conditions of the region.

The rapidity with which land was put under cultivation in the five leading hard red winter wheat states from 1900 to 1930, as given in the U. S. Census reports and Year Books of the U. S. Dept. of Agriculture, shows clearly what has happened in the region. In 1900 the total acreage under cultivation in the five states of Colorado, Kansas, Nebraska, Oklahoma, and Texas was 56,100,000. The acreage under cultivation increased to 70,000,000 in 1910, to 83,300,000 in 1920, to 88,600,000 in 1925, and to more than 97,400,000 by 1930. Much of this increase in acreage of tillable land, almost 74% or 41,300,000 acres, took place in the western part of the region, although much virgin land was broken in the eastern portion during and immediately following the World War. Texas and Oklahoma accounted for more than 24,000,000 acres of the total placed under cultivation during this period of 30 years.

Although there was an increase of almost 74% in the acreage of all crops under cultivation from 1900 to 1930, there was a much greater percentage increase in the acreage of wheat.

In these five states, 9,300,000 acres were devoted to wheat in 1900. This acreage was increased by only about 250,000 by 1910, but by 1920 it had increased to 17,850,000 acres. In other words, the acreage seeded to wheat practically doubled from 1910 to 1920. There was an increase in the area of land used for wheat of approximately a million and a half acres from 1920 to 1925. During the next five years, 1925 to 1930, there was a greater increase in the rate at which the land was placed in wheat production, especially in Kansas and Texas. By 1930 there was a total of about 24,900,000 acres used for this crop in the five states as contrasted with 9,300,000 acres in 1900. This is an increase of 15,600,000 acres of wheat in a period of 30 years and about one-half of the increase took place during the last 10 years of the period.

Throughout the entire region there should be a reduction in the total wheat acreage to aid in stabilizing production and farm income, to bring production more nearly in line with demand, and to conserve soil fertility and soil moisture. From experiences of the past and from present indications it appears that the total wheat area of the region should be reduced by approximately 5,000,000 acres or about 20%. Although this is an enormous acreage to remove from wheat production, it is believed that the total is not excessive in view of the welfare of the future agriculture of the region. The reasonableness of this recommendation is shown by the fact that several million acres of land unsuited for wheat production have been brought under cultivation and seeded to this crop.

The wide variation in soil and climatic conditions of the hard red winter wheat belt makes it impossible to adapt any land use program to the entire section. This makes it desirable to divide the

region into several sections, each of which should be considered separately because of variations in crop adaptation. The average annual precipitation for the area varies from about 35 inches in the eastern portion to approximately 15 inches in the western portion. Evaporation from a free-water surface varies from approximately 36 inches for the growing season in the eastern part to about 52 inches in the southwestern section. The altitude ranges from approximately 1,000 feet to more than 5,000 feet. The soils vary from heavy silty clay loams to sands.

For convenience of discussion the region will be divided into three sections—eastern, central, and western. Each of these will be subdivided to some extent, especially where wide variations in soil exist.

THE EASTERN SECTION

The eastern section represents that portion of the region where climatic and soil conditions are favorable for a more general type of agriculture. In this section alfalfa, sweet clover, and tame pasture grasses may be grown successfully. Straight wheat farming should not be practiced in this section, and it is here that the greatest change from wheat to other crops should be made. Within this region extensive areas of sloping, rolling, and even hilly land were broken and used for wheat production during and immediately following the World War Much of this land has remained in wheat. Soil erosion has removed much of the surface soil on the steeper slopes and the subsoils are being exposed. The nitrogen and organic content of these soils is being reduced at a rapid rate. These steeper slopes must be returned to grass for pasture purposes or be planted to other soil-binding crops in the near future or they will become so low in fertility and water-absorbing capacity that they will be of only limited value. On the level or the gently sloping soils in this section sufficient land should be seeded to permanent and temporary pasture to meet the grazing needs of the livestock normally produced in the area. The pastures are so limited in extent on practically all farms that there is not sufficient grass to meet the needs of the livestock except during the most favorable seasons. This condition has led to over-grazing which has resulted in a decided reduction in the carrying capacity of the pastures and on many farms the pastures have been denuded of practically all native grasses.

In this eastern section a shortage of feed for livestock frequently occurs during the winter period. By removing some of the land from wheat and using it for the production of corn and sorghums in the northern portion of the area and for sorghums farther south, the feed situation would be greatly improved. As an aid in improving the fertility of the soils and in producing high-quality wheat, sweet clover should have a more permanent and more definite place in the agriculture.

THE CENTRAL SECTION

The central section represents that portion of the region which produces a high percentage of the hard red winter wheat. Wheat production is more dependable in this section than farther west.

However, failures are too frequent to permit a stable agriculture to be built on continuous wheat production. The topography of the land encourages the use of a heavy type of power equipment and extensive wheat production. A large proportion of the level and gently sloping land has been brought under cultivation and in some parts of the area the steeper slopes and rolling lands have also been broken. The more level areas are better adapted to the production of wheat than to any other crop, with the exception of the sorghums. For this reason wheat undoubtedly will and should continue to be the chief source of cash income.

The more sloping areas are not well adapted to the production of wheat or any other cultivated crop because a high percentage of the rainfall is lost through surface runoff. Erosion is also seriously injuring the soil. It is difficult to determine what use should be made of these steep slopes. It has frequently been said that they should be returned to grass, but the re-establishment of grass in a practical manner on large areas is difficult or impossible. Economical means of re-establishing the native buffalo, grama, wheat and blue stem grasses have not been devised and tame grasses adapted to the region are not available except perhaps in the more northern portions. An economical use of such lands appears impractical until grasses that are adapted to the region are developed or introduced or until more practical methods are devised for re-establishing the native grasses.

The wide range of crop adaptation on the sandy soils, on the one hand, and on the heavier types, which consist largely of silt loams and silty clay loams, on the other, makes it desirable to divide the section into two portions based on soil differences.

The heavier types of soil throughout the entire section are well adapted to the production of wheat, to the production of corn and barley in the northern portion, and to the production of the sorghums in the southern portion. Corn fails so frequently on these soils in the southern part of the section that it is desirable to replace corn with grain sorghums to a considerable extent. Throughout the entire area on the heavier soils the acreage used for the production of the sweet sorghums usually is not sufficient to meet the forage needs of the livestock. The lands have been broken so extensively that there is not sufficient pasture remaining to supply grazing for the livestock and at the same time maintain the pastures.

Since moisture is the limiting factor in crop production, a portion of the wheat should be seeded on fallow land each year. A higher percentage of the wheat land should be summer fallowed in the northern portion of the section than in the southern.

The problems may be met partially and the agriculture made more stable by decreasing the acreage used for wheat production and devoting the land taken out of wheat to the production of feed crops and to summer fallow. An increase in the acreage of grain and forage sorghums for winter feed and of Sudan grass for summer pasture would aid materially in solving the feed problem. Complete wheat failures also could be largely eliminated by growing a portion of the wheat on fallowed land. In those areas where considerable livestock is produced and where spring-seeded small grains are not adapted,

fallow is also the most practical intermediate step in changing the land from sorghums to wheat. A year of fallow may be followed successfully by two or three years of wheat after which the land may be returned to feed crops or to fallow.

That there are many farmers within this section who produce no crop other than wheat and who will no doubt continue to do so for many years to come is certain. Because of the wide fluctuations in annual and seasonal rainfall these men frequently experience a total crop failure. Under this type of agriculture at least one-fourth of the cultivated land should be removed from wheat production each year and be used for summer fallow. If such a system were practiced the total production of wheat would be reduced materially during favorable seasons when high yields are secured almost regardless of the tillage method used and total failures would be greatly reduced during unfavorable seasons. Objections have been raised to the use of summer fallow in this section because of the danger of increasing the tendency of soil erosion by wind. This is not a valid objection because wind erosion will be reduced rather than increased when fallowed fields are properly prepared and managed.

The sandy soils in this section cannot be classed as good wheat lands and the acreage of such soil devoted to this crop should be reduced. Such land taken out of wheat production should be used for the production of corn and sorghums for grain and forage and Sudan grass for pasture. These soils are more subject to erosion by wind than are the heavier types and for this reason are more difficult to manage under fallow. Because of this condition, wheat on these soils should follow wide-spaced row crops or wheat rather than a clean fallow. As soon as grass adapted to these soils is available, the more sandy areas should be returned to pasture. The longer these very sandy soils are under cultivation, the greater menace they become to the agriculture of the surrounding areas and they also become more subject to extreme injury by wind erosion.

THE WESTERN SECTION

The western section of the region consists of that portion having the lowest annual rainfall and frequent periods of extended drought. Complete crop failures are relatively common and considerable abandonment of wheat occurs in some portions of the section nearly every year. It was in this section that the greatest expansion of the wheat acreage took place between 1920 and 1930. Because of frequent crop failure, light rainfall and relatively frequent droughts resulting in great expanses of unprotected soils, soil erosion by wind occurs more frequently and more extensively in this section than in the more eastern portions of the region. The adverse climatic conditions make it difficult to plan a satisfactory land utilization program for the section.

It has been said rather frequently during the last few years that much of the land in this section should have been left in native vegetation, that much of it is submarginal, and that it should be returned to pasture. The fact remains, however, that much of the land has been broken from the sod and that there are many successful farmers in the region. Previous to the recent period of drought through which

this section has been passing, these lands were not spoken of as submarginal and with the recurrence of periods of normal rainfall this section will again be regarded as an important part of the hard red winter wheat belt. Wheat production, however, is extremely hazardous in most of the area. For this reason the individual who depends upon wheat as his only source of income should have sufficient reserves to enable him to withstand two or three consecutive years of crop failure. He must realize that there is little opportunity for stability and little or no chance for continuous profitable annual production.

Because of the adverse climatic conditions and the hazards of wheat production, a land use program for this section should provide for a greater diversification of income through a greater use of row crops, chiefly sorghums. It should also provide for soil management and tillage methods that will aid in preventing soil erosion by wind.

The wide variations in crop adaptation of the sandy lands and the heavier soils make it desirable to divide the section into two areas based upon these two groups of soils.

The heavier soils are better adapted to wheat production than are the sandy types, but even in the more favorable locations on the best soils, crop production is hazardous and low and unprofitable yields and crop failures are relatively common. Only the more level lands in this area should be used for wheat production. The sloping and rolling areas that have been broken lose a high percentage of the rainfall by surface runoff, making it difficult to store sufficient moisture in the soil to insure a crop. When the soils are not properly managed, become dry, and there is not a cover of vegetation, they are subject to destructive erosion by wind.

For the future welfare of the soils and the agriculture of this region the more sloping and rolling lands and a portion of the more level areas should be returned to grass as soon as seed of adapted varieties is available and economic means have been devised for the re-establishment of grass cover. Previous to the development of such grasses and methods, it will be necessary to depend upon annual pasture, hay, and other forage crops and to manage the soil so as to conserve as much of the rainfall as possible.

The acreage seeded to wheat annually in this section should be reduced more than one-half and the land taken out of wheat production should be used for summer fallow and for the grain and forage sorghums in the southern portion and for corn and early maturing forage sorghums farther north. The agriculture on these heavier soils can be made more dependable and more permanent by a systematic use of summer fallow. The fallow should be used not only for wheat, but also for the grain and forage sorghums. In general wheat should not be seeded on these soils except when summer fallow has been practiced. This means than one-half of the wheat land should be summer fallowed each year. A part or all of the acreage of grain and forage sorghums, including Sudan grass for pasture, should be planted on fallowed land. The objection is frequently raised in this section as well as farther east that summer fallowing increases the susceptibility of the soil to erosion by wind. Again, this objection is

without foundation because land that has been properly summer fallowed is less susceptible to erosion by wind than is most of the land that is not fallowed and has no vegetative covering because of a lack of soil moisture.

The sandy soils of this section occur primarily in the southwest portion of the hard winter wheat region. They present some serious and difficult problems in land utilization. Most of these soils should never have been broken from the native sod partly because of the nature of the soils and partly because of the climatic conditions under which they exist. They are not adapted to wheat production and as a rule should not be used for this crop, although in the past great areas have been seeded to wheat The low growing or dwarf types of grain sorghums, the early maturing varieties of the sweet sorghums, and Sudan grass should occupy most of the acreage of the cultivated sandy soils. In some areas corn is perhaps almost as dependable as the grain sorghums. These row crops should, under most conditions, be planted in wide-spaced rows with a smaller amount of seed per acre than is commonly used. If wheat is grown it should be seeded between the wide-spaced rows. A high percentage, if not all, of these sandy soils should be returned to grass. It must be recognized, however, that methods have not been developed for seeding or otherwise re-establishing grass cover under such conditions.

These sandy soils are extremely subject to erosion by wind and the longer they are under cultivation the more susceptible they become to this injury. In some sections they have become so severely eroded by wind that they have little or no value for economic crop production As long as such soils are without protective covering they are a constant threat to surrounding areas. The immediate problem is to establish cover of some type on these lands and then plan to re-establish a permanent type of vegetation as soon as economical methods are available.

SUMMARY

In presenting a regional land use program for the hard red winter wheat belt the following points have been considered:

1. The region is adapted to extensive farming which encourages a speculative type of agriculture.

2. The program on land use should plan to conserve the soil and water resources and aid in stabilizing the agriculture of the region.

3. The area under cultivation in the five leading hard red winter wheat states increased from 56,100,000 acres in 1900 to more than 97,400,000 acres by 1930. The area devoted to wheat increased from 9,300,000 acres in 1900 to 24,900,000 acres in 1930.

4. Much land that is too rolling, too sandy, or located in regions too deficient in rainfall for successful crop production has been placed under cultivation.

5. For the welfare of the agriculture of the region, it appears that the total wheat area should be reduced by approximately 5,000,000 acres or about 20%.

6. The land removed from wheat production should be used for soil-binding and soil-improving crops, pasture crops, and feed crops in the eastern portion of the region. In the central portion it should be used for increasing the acreage of feed crops and for summer fallow. In the western portion it should be used for a material increase in the acreage of sorghums and other row crops and for summer fallow.

7. One of the greatest needs of the region is the development or introduction of a grass or of grasses that may be used to re-establish sod on the sandy areas and on the sloping and rolling lands

SOME PROBLEMS OF LAND USE IN THE CORN BELT[1]

P. E. Brown[2]

"'WESTWARD the course of empire takes its way' with ruined lands behind." I cannot on this occasion resist repeating this often-quoted paraphrase of an age-old line, just as it was uttered so trenchantly many years ago by that pioneer Corn Belt proponent of the theory of planning a permanent agriculture, Hopkins of Illinois. To him more than to any other single individual we can trace the beginnings of the theories and practices of soil conservation as designed to fit Corn Belt conditions.

For some years we waged an uphill battle to bring about any general recognition of the fact that "soils will wear out". It took time even to win a hearing for such a "bear story" with many Corn Belt farmers. They were still farming rich Corn Belt land and growing good crops and they simply refused to get excited about methods of soil management and the depletion of soil fertility. They were making good profits. Why worry?

But some progress was made and a few farmers here and there who were more receptive to new ideas were induced to try out the things the "college professors" were suggesting. They did this probably with their fingers crossed, and to their surprise the treatments were found to be worth while. Such tests often served as demonstrations and these, along with experiment station publications giving the results of experimental work, and much extension activity, gradually led to some interest in the land and its management.

About this time it began to be apparent to many farmers that their soils were becoming depleted in fertility. They found that their crop yields were declining. They noted that it had become increasingly difficult to grow clover and was often quite impossible. They were also painfully aware that their incomes were decreasing, and while they were inclined to attribute this to politics or to the party in power, they were forced to admit that it was partly due to lower crop yields per acre on their lands. They were obliged in many cases to plow up more land to plant to corn in order that they might grow enough to supply feed for their livestock. This often meant that the washing away of the soil became progressively greater and greater. So the depletion in fertility and the erosion losses on individual farms soon reached a point where farmers were becoming alarmed over the situation. The thought began to take shape in our minds that the problem was becoming too serious to be handled by the individual farmer and that state or national action would ne needed if we were to avoid a condition of bankrupt farmers on bankrupt land—a bankrupt agriculture.

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[1]Journal Paper No. J314 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 363. Also presented as part of a symposium on "Regional Land Use" at the annual meeting of the Society in Chicago, Ill., December 5 and 6, 1935.

[2]Head of Department of Agronomy, Iowa State College.

And then along came the depression. The stage was all set agriculturally for a real show and that is just the sort of a show it was. The foreign markets had disappeared and the domestic market was toppling, but the farmers went on producing more and more agricultural products as prices declined in the vain hope of selling enough in quantity to offset the low receipts. Naturally, a great surplus appeared and then there was no market at all and the situation of the farmers became desperate. In fact, the whole country was plunged into the depths of despair. There were millions unemployed and starving, literally in the midst of plenty, or at least in the midst of a great surplus of agricultural food supplies. What a curious and anomalous situation. There was no time to investigate causes nor to speculate on how it might have been avoided. The important thing was to find out what to do about it. Many suggestions were offered and some remedies were tried with little or no effect and for some time the situation looked hopeless. "Prosperity was just around the corner", but the corner seemed to keep moving further and further away. But I need not digress to discuss the measures adopted for the relief of agriculture. Suffice it to say that we have come a long way from the depths of the depression, and we began to "bog our way out" just as soon as it was recognized that a "pink pill would not cure a broken leg", and some drastic measures were taken.

Now comes the question where land use and soil conservation fit into the picture. At first thought it seems a curious tie-up Why should conservation and land use be included in a program for farm relief? In the first place it may be pointed out that soil erosion was just being brought to public attention as a grave menace to our agricultural lands under the impassioned representations of that apostle of erosion prevention and control, Hugh H. Bennett, and some interest in the problem was appearing even in the Corn Belt where the effects were beginning to be noted. Indeed it was actually suggested in some of the early discussions of farm relief that the thing to do was to let erosion go on uncontrolled and the surplus of farm products would soon disappear and there would be an automatic control of production. But saner counsels prevailed! A wave of public sentiment spread over the country like wild-fire to stop the destruction of the agricultural lands The general interest in erosion control became so great that it could not be overlooked in agricultural discussions.

And then, too, it may be recalled that many of the agricultural leaders had been talking about the need for a new land policy for at least 10 years before the National Conference on Land Use held in Chicago in 1931 and nationwide plans along this line began. The importance of a land use program was certainly in the minds of many people. Finally, it was becoming apparent to many farmers and others that soil depletion, reduced fertility, low yields, abandoned farms, mortgaged land, tax delinquency, and corporation ownership of farms were all reaching alarming proportions and a general decline of agriculture in the Corn Belt and in other parts of the country was seriously threatened.

Perhaps it is no wonder, therefore, that in the plans for agricultural

rehabilitation as they began to take definite form, land use and soil conservation began to appear. But it is certainly amazing the way these subjects have been taken up, developed, and put into operation. The literal adoption of both as integral parts of the recovery program has led some people to believe that they actually originated with the "New Deal", which is not true at all.

The situation today is indicated in the following quotation taken from the daily paper of this morning (November 17) which has come to my attention as I write: "Soil Conservation as a means of solving the farm problem has come, at least temporarily, to overshadow other plans of farm relief this year. . . . The acceptance of soil conservation and proper land use as an approach to the farm problem is recognition of the long-time view of agricultural needs instead of merely the emergency consideration which has been foremost in much of the arguments and agitation of the past."

It is interesting to note also in this connection that at a conference in the Corn Belt this past summer, it was agreed that "in the Corn Belt it (the adjustment) centers around the feed-grain livestock problem The primary problem is to determine the ratio of feed to grass and other crops which will *most effectively conserve land resources* and at the same time permit as large a production of livestock and its products as will result in maximum net returns under existing and prospective demand conditions."

GOOD AND POOR LAND IN THE CORN BELT

Now we do have much good land in the Corn Belt still. In fact, from the report of the National Resources Board it appears that there is in the Corn Belt over one-half of the Grade 1 land, or 59 million acres out of a total of 101 million acres in this grade in the country as a whole. While, on the other hand, we have less than one-sixtieth of the Grade 5 land, or the poorest, or 14 million acres out of 881 million, we do have some submarginal land.

It may be mentioned, too, in this connection that according to the recent reconnaissance erosion survey of Iowa, 87% of the farm land in the state was found to be suffering from sheet and gully erosion in various degrees. The fertile topsoil is being washed away from more than half of the farm land (54%) at an annual rate which seriously endangers the productivity of the land. Similar figures would undoubtedly be obtained for other parts of the Corn Belt. This means that there will be a rapid increase in Grade 5 land throughout the Corn Belt unless a land use program is adopted which will prevent the occurrence of erosion.

We must consider, then, these two very important points in connection with the problem of land use in the Corn Belt. First, that we still have a large acreage of land which is rich and productive and which is *worth saving*, land on which there is still some topsoil remaining and some fertility to conserve. And, second, that we have some poor land, some submarginal areas which we must do something about.

SUBMARGINAL LAND USE

Taking up first the problem of these submarginal lands, it may be mentioned that they are defined as "not adapted for use for farming" which is perhaps too broad a definition. There are various other definitions and many variations in the concept of what constitutes submarginality. But whatever definition is accepted, it is apparent that there are many angles to the question of what to do with submarginal land. The purchase of such land by the government and the removal of families to other more productive areas was one suggestion. This proposal aroused much interest especially among land owners who had invested "not wisely but in too poor land". I understand that the government had an opportunity to buy up practically all of one of the western states (not California). So-called submarginal land in the Corn Belt could not compete in such a program. Our poorest land looked good to those who had just examined some of the lands just outside the Corn Belt. But we do have land in the Corn Belt which will not permit a farmer to prosper even under the most favorable price conditions. Such land might be purchased and taken out of production, of course, but there are difficulties in the way, in addition to the real problem of funds. What to do with the families is a grave question, and in general, the economic and sociological aspects of the situation are very important.

Then, too, such land might be purchased by the Forest Service and used for forest plantings and reforestation. This has been done extensively in some areas outside of the Corn Belt and to a limited extent in it. The land may be taken over for recreational purposes for state or national parks or for game preserves. This has also been done in a small way in the Corn Belt.

But there are real difficulties in all these usages, the chief one being that the poorest land in the Corn Belt is apt to be held at a higher figure than land in other states and the price factor is a serious deterrent to much help in these directions.

The agronomic solution of the problem is the seeding down of submarginal areas to permanent pasture. But the seeding down of large areas of land to permanent pasture, and especially of large proportions of the land on a farm, may mean a change in the system of farming. It may mean a change from corn-hog farming to beef cattle, dairy cattle, or sheep, for example. There are real difficulties in such a shift, some being economic and some personal or sociological. We have been told that the size of the farm is an important deterring factor to the seeding down of land to pasture and it has been recommended that some plan be devised for the consolidation of farms. But this again brings up the problem of what to do with the people who are moved off the small farms. In fact, it is almost impossible to evade the economic and sociological difficulties which arise in all such adjustments in land use.

Without going into the economic implications, however, it seems apparent that if the submarginal lands are not purchased by the government for retirement from cultivation, for forest purposes, parks, or game preserves, they should be put into permanent pastures just as far as possible. Then we must take steps to try to make that pasture

land as productive as possible. The proper management of such pastures on poor land is one of the problems which we are facing now and some practical recommendations along this line are sorely needed.

A LAND USE STUDY IN IOWA

In connection with the utilization of the good land in the Corn Belt and the planning for such use in the future as will conserve the soil and permit of a permanent agriculture, I wish to present briefly the results of a preliminary study of land use made in Iowa last year by Professors Firkins and Smith of our staff and consider some of the agronomic problems arising from that work.

The objective was to determine the acreage of the various soil types in each township in every surveyed county and to assign to each a specific rotation which would conserve fertility and prevent erosion of that type. These rotations were selected from a carefully chosen list of 12 standard rotations as shown in work sheet 1A.

WORK SHEET NO. 1A.—*Standard rotations upon which recommendations are based.*

Rotation No.	Crops
1	Corn, Corn, Small grain, Legume hay
2	Corn, Small grain, Legume hay
3	Corn, Corn, Oats, Mixed hay
4	Corn, Oats, Mixed hay, Rotation pasture
5	Corn, Corn, Small grain, Sweet clover (level Marshall-Clarion)
6	Corn, Corn, Small grain, Winter wheat, Clover
7	Permanent pasture
7x	Woodland not pasture
8	Special crops
9	Corn, Soybeans, Winter wheat, Mixed hay, Rotation pasture, Rotation pasture
10 (a) ½	Corn, Corn, Small grain, Clover
(b) ½	Corn, Small grain, Winter wheat, Mixed hay, Rotation pasture
11 (a) ½	Permanent pasture
(b) ¼	Corn, Oats, Alfalfa, Alfalfa
(c) ¼	Corn, Soybeans, Oats, Clover
12 (a)	Corn, Corn, Small grain, Winter wheat, Alfalfa
(b)	Corn, Corn, Oats, Alfalfa, Alfalfa, Alfalfa

It was assumed that lime should be applied to about 10% of the acid soil area to permit of the use of desirable crop rotations which include legumes requiring basic soil conditions. It should be noted that occasionally any one of several rotations might prove entirely satisfactory for certain soils and choosing one was therefore somewhat an arbitrary matter, just as liming 10% of the land was quite arbitrary. But the rotations were very carefully selected and fitted to the various soil types as maintenance rotations for those types on the basis of a full and rather complete knowledge of the characteristics of the soil types, the topographic position, and the present use of the types.

The exact acreage of each type in all townships in surveyed counties was determined by planimeter measurements on the soil maps. Then the rotations were fitted to the types as indicated in work sheets 1 and 2.

WORK SHEET NO. 1.—*Township data on crops and soils recommendations.*

Blackhawk County Eagle Township Key No. 7-16

DATA FROM CENSUS 1930

No. of farms 109 Acres in farms 22572 Crop Land 16560 Plowable pasture 2929 Woodland pasture 249 Other pasture 1706 Woodland not pasture 22 All Others 1106 Area in corn 8470 Small grain 2067 Pasture total 5176 Pasture permanent X Hay legume 416 Hay mixed 1555 Other hay X Green manures X Woodland not pasture X Special crops 193 All other X Total hay 2062.

DATA FROM SOIL MAPS: SOURCE

Names of soil types	Grade	Area	Deduct Bldgs., etc.	Net area	Recommended rotation
Tama silt loam	1			17,009	1, 6, 9
Clyde silty clay loam	8			2,583	7, 1
Carrington loam	1			826	1, 2, 11c, 4
Waukesha silt loam	1			767	1
Meadow	10			193	7
Dodgeville silt loam, shallow phase	8			64	7
Muck	10			23	8

WORK SHEET No. 2.—*General crop and soils information on county.*
County: Blackhawk

Crop Land

1. Predominant Topography: Level to gently rolling. Cut by two rivers and their tributaries.
2. Erosivity: Slight to medium
3. a. Predominant Types: b. Productivity:
   Tama silt loam — High
   Carrington loam — High
4. a. Extent of Acidity: 85% b. Degree of Acidity: strong
5. Remarks: Large areas sandy—good for special crops
6. a. Pasture Types: Clinton, Carrington—Tama, Rolling Phase
   b. Lime? Yes c. Seeding mixture: Clover and timothy
7. a. Predominant Rotations: b. Acres: c. Kind of legume: Red clover

a. Predominant Rotations	b. Acres	
1	104,348	Soy beans—alfalfa—sweet clover
4	38,972	d. Kind of rotation pasture:
2	36,934	Red clover—timothy, sweet clover

PERMANENT PASTURE

1. Predominant Topography: Level to gently rolling
2. Predominant Type of Pasture: Upland
3. Approximate Acreage Woodland Pasture: 16,000

COMMENTS

There is relatively large area of waste land. The need of drainage is evident in many parts of the county. The area of bottomland is small. One of the first needs of the soils of the county is lime. Erosion occurs more extensively on Clinton and Carrington sandy loam. The terrace soils, as O'Neill, Bremer, Waukesha sandy loam and Calhoun, are in need of organic matter. Shorter rotations should be practiced

The rating or grade number for each soil type was that assigned to it in previous work carried out in connection with the soil survey and study of the soil type characteristics. The general crop data were taken from the 1930 census. Over three-fourths of the counties in the state have been surveyed and soil maps are available for them. Where soil survey maps were not available, the areas of the different types in the unsurveyed counties were estimated from the averages of the areas in adjoining counties having similar soils.

The changes in crops as finally recommended were given in percentages by counties and then summarized by type of farming areas in the state as defined by the economists. The changes for the entire state and for the various type of farming areas are shown in the Figs. 1 and 2.

It may be noted that the average reduction in corn acreage recommended for the state was 19.4% over that in 1929 and this is almost the same as the minimum 20% reduction requirement of the AAA. This close agreement between the calculated desirable reduction in corn acreage as arrived at by the AAA and the reduction needed for a sound fertility maintenance program in the state emphasizes in a very striking way the close relationship which might exist between an emergency program and a long-time conservation plan for land use.

It may be noted also (Fig. 3) that there is close agreement between the results obtained in this study by individual soil types

CLASSIFICATION OF SOILS BY GRADES, ROTATIONS, AND CROPS

Areas in crops under recommended rotation.

Grades	Rotation	Net area	Corn	Small grain	Pasture		Hay			Woodland not pasture	Special crops	All other
					Rotation	Permanent	Legume	Mixed	Other			
1	1	9,478	4,720	2,370			2,368					
1	2	207	69	69			69					
1	4	206	52	52	51			51				
1	6	4,253	1,701	1,701			851					
1	9	4,252	709	709	1,416		709	709				
1	11c	206	157	52			103					
8	1	1,291	646	323			322					
8	7	1,356				1,356						
10	7	193				193						
10	8	23									23	
Totals.		21,465	7,967	5,276	1,467	1,549	4,423	760			23	
Adjusted totals												

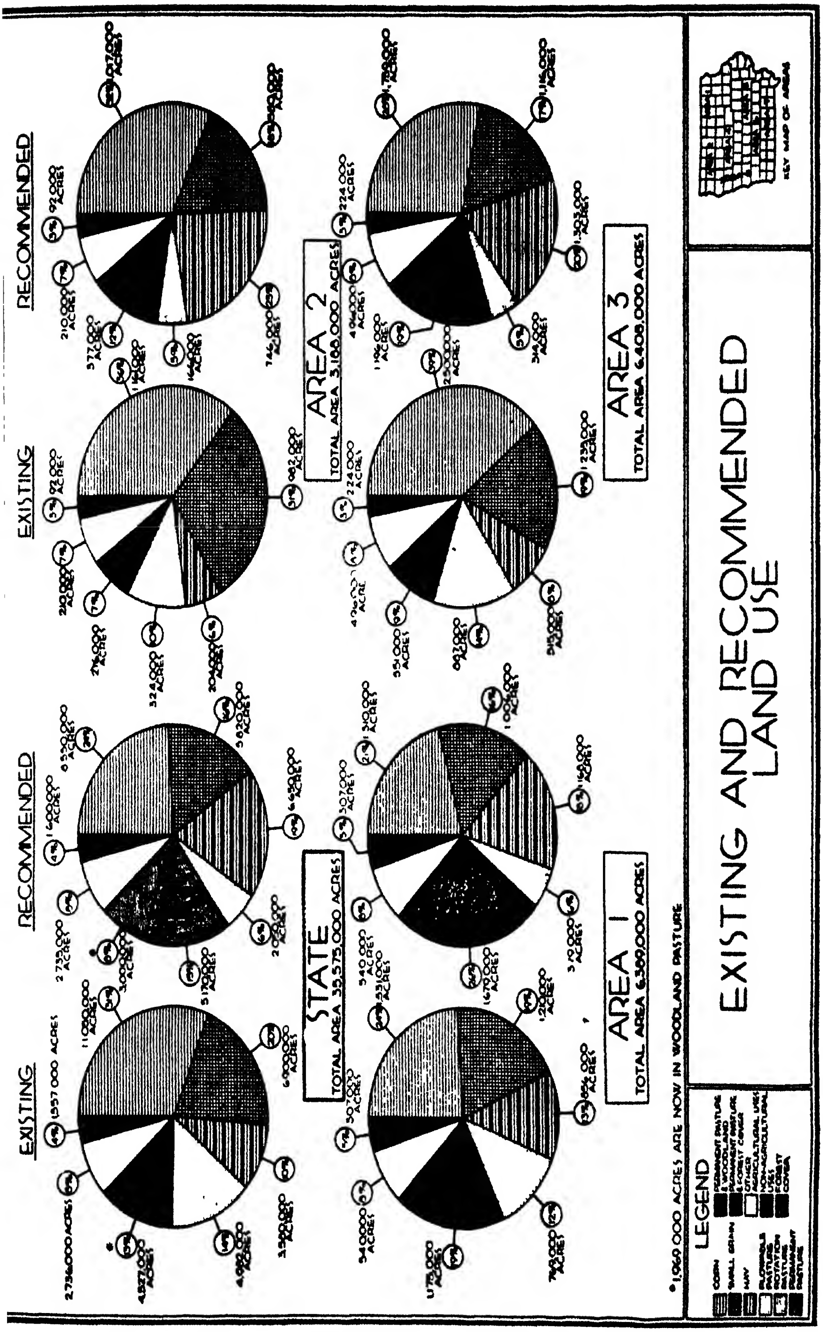
EXISTING
RECOMMENDED
STATE
TOTAL AREA 35,575,000 ACRES
AREA 1
TOTAL AREA 6,309,000 ACRES
AREA 2
TOTAL AREA 3,168,000 ACRES
AREA 3
TOTAL AREA 6,408,000 ACRES
EXISTING AND RECOMMENDED LAND USE
*1,060,000 ACRES ARE NOW IN WOODLAND PASTURE
LEGEND
KEY MAP OF AREAS

FIG. 1.

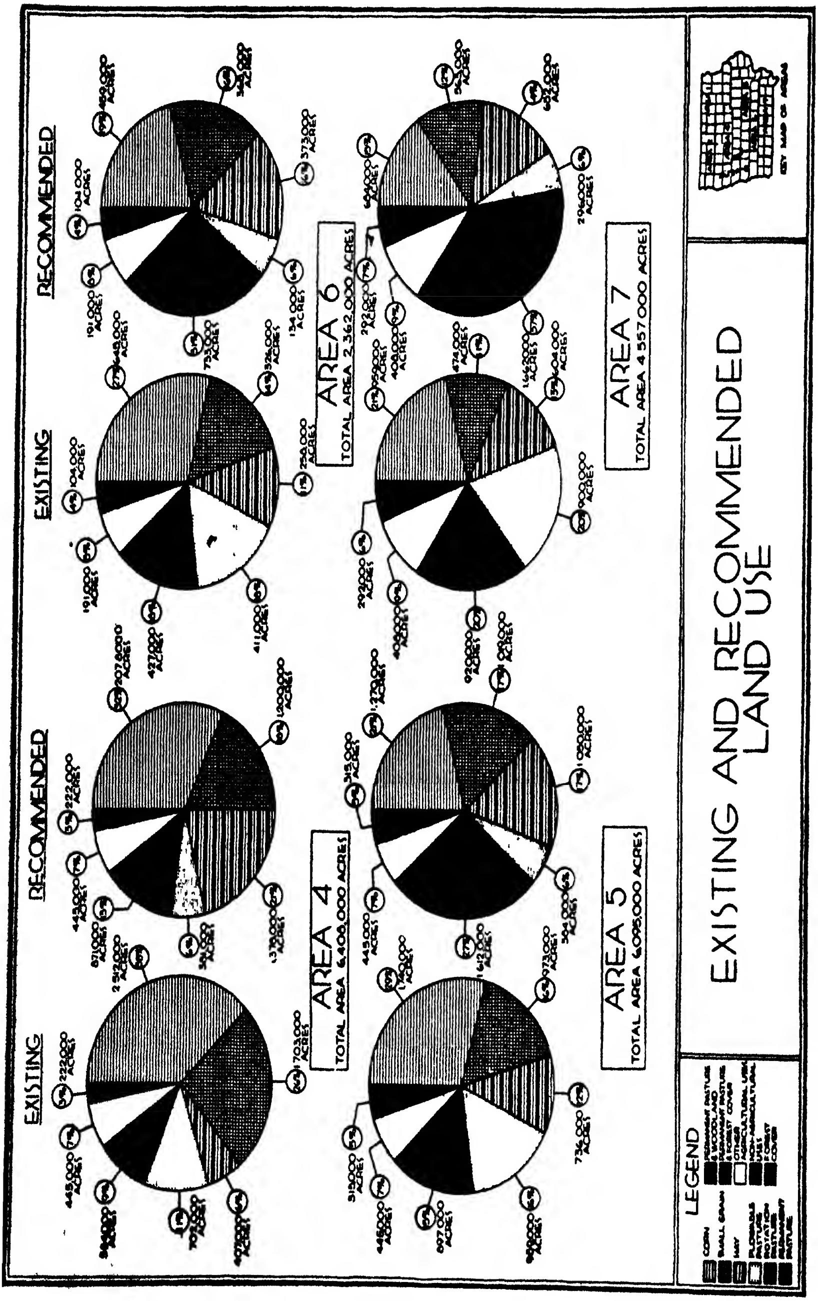
EXISTING
RECOMMENDED
AREA 4
TOTAL AREA 6,408,000 ACRES
AREA 5
TOTAL AREA 6,095,000 ACRES
AREA 6
TOTAL AREA 2,362,000 ACRES
AREA 7
TOTAL AREA 4,557,000 ACRES
EXISTING AND RECOMMENDED LAND USE
LEGEND
CORN
SMALL GRAIN
HAY
PERMANENT PASTURE & WOODLAND
OTHER AGRICULTURAL USE
NON-AGRICULTURAL USES

FIG. 2.

county by county and the figures which have been used for a number of years by our extension agronomists when presenting the subject of the need for more legume growing in the state and a smaller acreage in corn in order to permit of a maintenance of the fertility of the soil.

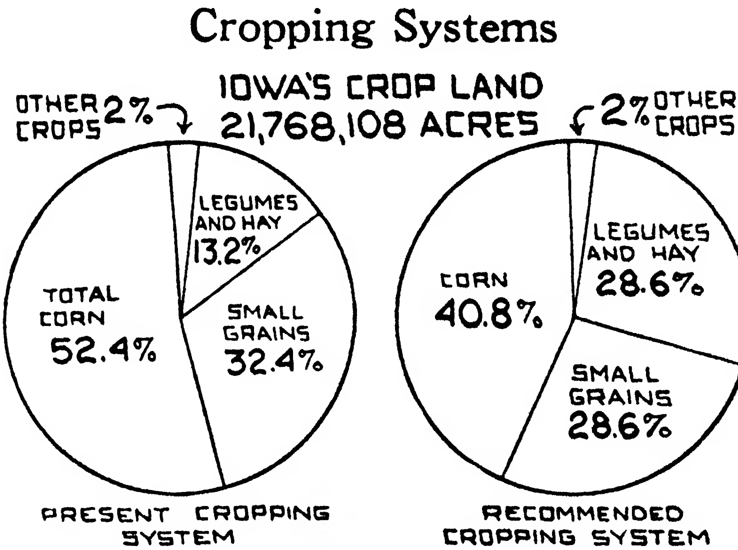

FIG. 3.—Present and desirable cropping systems in Iowa from the standpoint of soil fertility maintenance.

Then after the figures were derived for each county showing the desirable crop plan for each type, the livestock specialists took the crop production figures and transformed them into livestock systems for each county as a unit.

These recommendations from the agronomic and livestock standpoints were studied by the economists to determine the effects upon farm income, upon the systems of farming, upon feed unit production, upon the relative economic position of the various grains by counties, and finally upon a long-time adjustment program.

Now I wish to take up a consideration of some of the agronomic problems which have arisen out of this land use study and other work carried out in connection with the appraisal of land and the control of erosion. While there is no intention of minimizing the importance of the economic problems in land use, I am concentrating upon the agronomic problems, and indeed perfectly arbitrarily and with some difficulty isolating them from the economic implications.

THE SOIL SURVEY PROBLEM

The survey of the soils of an area has been quite generally agreed to be almost essential to a sound land use program. The question then arises what to do about areas which are not yet surveyed and cannot be for some years, if ever. What can be done toward land use in such cases? Perhaps reconnaissance surveys might provide the

necessary information. At least they would be the next best thing to a detailed soil survey. In some cases they might serve the purpose very well.

How to speed up the soil survey work is a grave problem in the Corn Belt as elsewhere. The pressure upon us for the data supplied by the soil survey is heavy. The problem has no answer, of course, except in increased funds for the work and a trained personnel to carry it out. There is a deplorable scarcity of men experienced in soil surveying at the present time and any increase in the amount of survey work, even if funds were provided, would be limited by the number of men available who have had the training necessary to enable them to handle the job. A few of the colleges are offering special courses along this line, as we are doing in Iowa, but we need more men than are being prepared.

Then in connection with the survey there is the problem of the scale of the maps. Shall we continue to map on the basis of 1 inch to the mile or shall we double that scale as has been suggested or go even to a still larger scale? For land classification and appraisal work can we use the same scale or should we have larger scale maps for these purposes? In farm appraisal studies larger maps have seemed desirable and even essential as a comparison of the two maps made of a sample farm appraised in this work will indicate (Figs 4 and 5). We are now comparing the use of maps made on two different bases in some land classification studies which are under way in the complicated drift area in Iowa.

THE EROSION SURVEY PROBLEM

The problem of making slope and cover maps as a basis for erosion control operations is a serious one. Should such maps be made as a part of the soil survey? How should they be constructed? What about the methods employed in such work, the basic assumptions made, and the interpretation of the data and maps when they are compiled and drawn?

The Soil Conservation Service has been making wonderful progress in answering these questions and we have been cooperating with them in the work. We need to have some further information in these connections, however, if we are to make erosion surveys as a part of the regular soil survey work, as a part of the surveys for land appraisal and land classification work, and especially if it is to provide the most information in connection with the planning of a permanent land use program.

THE PROBLEM OF RATING SOILS

The method employed by Dr. Marbut in obtaining a rating of the soils of the country for the National Resources Board is undoubtedly the best one at present available. We rated the soils of Iowa on that basis and obtained figures which have been very useful in many ways. But there are problems here. How can we rate the soils in land areas which have not had a soil survey? How can a rating of soils be made where erosion has been active and a vastly disturbing factor? How can a potential fertility rating which is really what we have

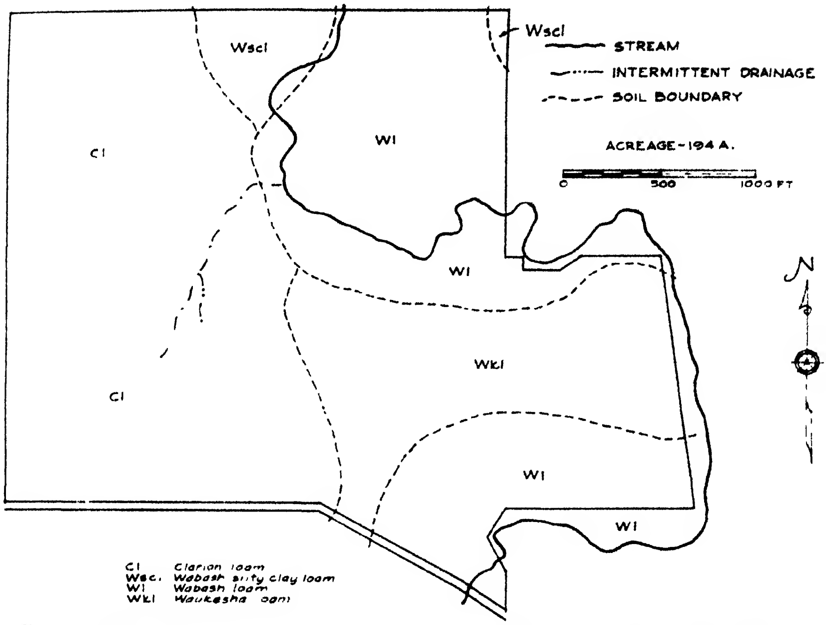

FIG. 4.—Map of farm A enlarged from county soil survey map, Iowa Agr. Exp. Sta. Bul. 326.

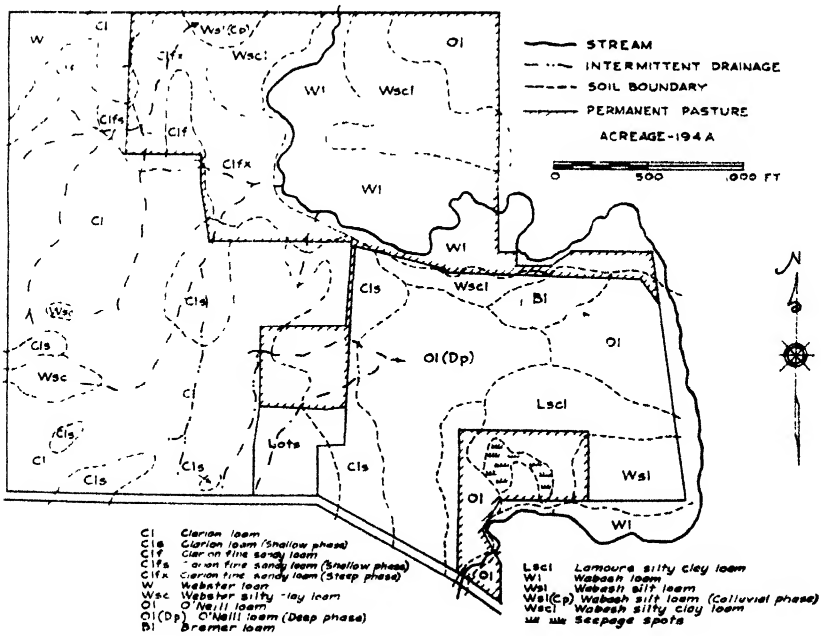

FIG. 5.—Map of farm A on the scale of 8 inches per mile, Iowa Agr. Exp. Sta. Bul. 326.

devised, or perhaps it might be called an average rating, be adapted to fit field conditions? That has been a problem in appraisal work and a flat, inelastic use of potential ratings has caused some difficulties. In the rating of farm land, for instance, Murray and Meldrum take into account the soil, the drainage, the topography, the erosion and the potential ability of the soil to produce crops. Then they make crop yield estimates with all these things in mind. Obviously, they would arrive at quite a different figure in many cases if they merely considered the potential rating of the soil. In other words, a No. 1 soil is not always in a No. 1 condition of fertility due to poor management, erosion, or for some other reason. Poor systems of soil management with consequent depletion in fertility and losses by erosion are the chief reasons for low ratings of potentially good soils. Studies along the line of fertility ratings are now under way and some method may be devised for measuring the variations in the soil types from the typical, and then by applying these variations to the potential ratings, they might be modified to fit the actual field conditions. There is no question of the value of soil ratings, but we need more information to aid us in making a proper interpretation or adaptation of them.

EROSION CONTROL AND PREVENTION PROBLEMS

The multitude of problems connected with the control and prevention of erosion is engaging the attention of the Soil Conservation Service and many other agencies and extensive demonstrational and experimental work is under way. But there are numerous problems along this line which need solution in connection with a land use program in the Corn Belt as elsewhere. I need only mention a few to indicate the importance of additional work in this field The relative effects of various crops on erosion in different soils and the erosion-preventing efficiency of individual crops and various rotations are extremely important questions. When and how strip cropping may be efficient and the value of contour farming are significant problems. The beneficial effects of organic matter, of liming, of fertilization, upon various soils in relation to erosion prevention should be determined. How to determine soil erosivity and how to measure the soil characteristics which operate in this connection are very pressing problems in connection with the adoption of methods of erosion control in individual cases. The engineering problem of types of terraces is closely related to that of when to terrace and when it is not necessary or not even desirable. How to maintain terraces is an agronomic problem, but this will not be solved until the engineers are brought to a realization of the importance of the soil type and the soil conditions upon the construction of terraces. The best agronomic practices cannot save some terraces as has been amply demonstrated in some states and, on the other hand, terracing without proper handling of the soils and crops cannot hope to succeed.

The forestry problem of planting trees has little agronomic significance except indirectly, but it is important to know when land should be protected from erosion by reforestation and when by seeding down to permanent pasture. This problem, however, is far from a solution

as there are economic questions involved for which answers are probably a long way in the future.

I would emphasize further the fact that it is quite impossible to say what method of erosion control should be followed for each individual soil type, yet that is a question which has been frequently asked. It must be remembered that the method of soil management in the past may make all the difference in the world in the particular method of handling the land which will be required to prevent soil washing. Incidentally, we are attempting to develop at the present time some alternative suggestions for handling various soil types to control erosion on the basis of the slope, the cover, or extent of erosion which has occurred and taking into account the different methods of management which will be required because of the past mismanagement of the land.

THE PASTURE PROBLEM

When land should be seeded down to permanent pasture in order to prevent erosion and maintain fertility, is one of the very practical problems in erosion control and in land use plans. It is directly related to the efficiency of a good rotation in conserving the land, to the erosivity of the particular soil and also to the questions of the returns to be expected from pastures and of methods of management to permit of permanency and a supplying of an abundant pasturage. When will rotation pastures serve the purpose of conservation and take the place of a permanent pasture is an important practical question.

Then there are the problems of pasture establishment and handling, which must be considered. Overgrazing is certainly one of the most common causes of poor pastures as has been shown in recent studies. But how to keep a pasture in satisfactory condition under controlled grazing is largely a matter of treatment, or fertilization and reseeding. Considerable educational work is necessary in connection with pasture management to emphasize the fact that permanent pastures are crops which require just as careful attention and just as many precautions in handling as any other crop. There must be a general recognition of the value of pastures in providing feed and of the fact that fertilization of pasture may pay well, before there will be any extensive practice of the principles of proper pasture management.

There is now a changing viewpoint regarding pastures and their value and place in general farming operations and this means that they are looming larger and larger and much less ominously in the land use picture of the future. To plan to put the land into permanent pasture to prevent erosion, permit of conservation, and provide for a proper land use, no longer virtually means taking it out of consideration from the farm standpoint. It is certainly specious reasoning to say that because the income from pasture land is less than that from crop land, therefore we should not recommend the seeding down to pastures of land which is washing away rapidly and will not now produce a good crop. There is no economy in continuing to attempt to grow crops on land which is only suited for pasture.

And yet too much emphasis upon the economics of this situation has led to the idea that we should not suggest that land should go into pasture since that would change the type of farming and put the land to an extensive rather than an intensive use and because grass farming is less profitable than corn farming. The fallacy of the idea is apparent. How can it be profitable to try to grow corn on land which is so badly eroded and washed away that the yield is too low to warrant harvesting the crop? The land and its potentialities must certainly be taken into account in determining land use and we must not be over-awed nor over-persuaded by inadequate economic considerations. In many cases such as this they are quite secondary

THE ROTATION PROBLEM

The desirability of following a good rotation system in order to maintain productivity and protect the land from erosion has been an integral part of all good soil management teachings for many years. But in the Corn Belt the profit from growing corn and the need for this crop to provide feed for the hogs has led to the practice of growing just as much corn on the land as the operator thought "it would stand". The practically continuous growing of corn in some sections, such as southwestern Iowa, for example, has gone on for years and the natural fertility of the soils was so great that good crops are often still being obtained. But mostly the "corning" process is beginning to show its effect and this is especially true since measurements of the extent of sheet erosion have been made.

While in our Iowa study of the adjustment of crops to fit the soil types, we used all knowledge available and our best judgment in selecting the rotation for maintenance, we are well aware of the fact that there are undoubtedly other rotations just as good as the ones used. No one knows what is the *best rotation* for any particular soil and set of soil conditions. So one of the great problems in land use is the selection of rotations to fit the varying soil conditions and the suggestion may be offered here that lists of optional rotations be prepared for individual soils, thus allowing modifications to fit individual conditions. The fact must be recognized that a rotation is not fixed and absolute for every soil type and given set of climatic conditions, but that there may be several arrangements of crops in sequences which would serve admirably for the same purpose.

THE PROBLEM OF ORGANIC MATTER

Directly involved in the rotation problem and indeed logically an integral part of it is the question of the maintenance of the organic matter content of the soil, for it is now recognized that even under the livestock system of farming legumes must be used as green manures if the farmer is to keep up the humus supply in his soil. No longer can it be accepted that "livestock farming will maintain soil fertility". That old idea has caused enormous damage to many agricultural lands, especially in the Corn Belt, yet we often hear the statement. But the fact that livestock farming will not maintain fertility is demonstrated on every side of us throughout the Corn Belt. In the midst of good livestock farms, good from the livestock standpoint, we find soil depletion and erosion and often a general

run-down condition of the land. And that is true in spite of the fact that more land is of course in pasture on such farms and some attempt is made to apply the manure produced to the land. There is some return of fertility to the soil in such cases, but it is *not enough*. Usually it is quite impossible to keep up the organic matter content of the soil with the farm manure produced since the amount available on an average farm will not permit of even a small addition to all the land once in the rotation. It is necessary, therefore, to practice green manuring and the problem is what to use for green manures and how fertility may be maintained by the process.

How much organic matter and nitrogen may be added by certain crops, such as sweet clover plowed under in the spring, for instance, or by hubam clover or other legumes, are important questions. Then there is the problem of the artificial inoculation of legumes, when it is necessary and how it affects the nitrogen situation. The rapidity of the disappearance of the organic matter from soils under cultivation has a definite relationship to the maintenance of the supply in the soil. The studies on carbon dioxide production in soils have given us some help in this connection, but they do not answer the question fully. Perhaps it cannot be answered except for individual seasonal soil and crop conditions. This may also be true in the case of the nitrogen added by inoculated legumes such as green manures. And then when we try to balance the nitrogen we face the question of the losses, on the one hand, and the possible additions in the precipitation and by the non-symbiotic nitrogen-fixing bacteria, on the other, and these are problems needing solution.

THE PROBLEM OF LIMING

The value of liming in connection with the maintenance of soil fertility is generally recognized in the Corn Belt. The problem in this connection recently has been the lack of funds to permit farmers to purchase and apply lime. So liming has come into the picture in connection with the Soil Conservation Service program and also as a works relief project and an activity of the CCC camps. There is also a definite program under way in the newly organized county soil conservation associations in Iowa to provide limestone at as low a cost as possible in order to speed up the liming of the land so that the best legumes may be grown and the erosion losses may be cut down or even eliminated.

Liming has been accepted as one of the basic requirements of a land use program for a permanent agriculture and, although it has required vigorous defense on sundry occasions under the attacks of the uninformed, the program for the future includes liming and will do so. The problems of how much to apply, the form to use, and effects on many crops are not yet settled. Our recommendations have been to lime the rotation, which means to meet the lime requirement of the soil. We have not held any faith in the theory of small applications of lime for general use in Iowa. It may be all right for some soils and as a temporary money-saving device, but as a general method we have no evidence yet of its superiority or its general efficiency.

We hear much about acid-tolerant crops, but while such crops do grow on certain acid soils, they have been found by experiments in many cases to produce better growth when the land is limed and the liming proves profitable. In the case of certain of the legumes there appears to be a definite relation to nodulation and nitrogen fixation and to the nitrogen content of the plants from the liming operation. This is true of soybeans, for instance. I might mention also the question of the relative effects of magnesian versus non-magnesian limestones. We have not been able to find any appreciable difference in these two materials in general in Iowa, but there are undoubtedly cases where large differences would appear. Then there is the question of the purity and fineness or amount of fine material in the limestone as applied. Our work would indicate that the requirements of the Illinois Agricultural Association are about right.

Finally, there is the question of overliming, but frankly, we are not much concerned about this, for we recommend that lime be applied only when it is needed and in amounts indicated as necessary by the tests. When this is done there is little or no danger of an overly large addition. We have had no trouble from this standpoint in Iowa The old idea of applying limestone regularly in the rotation was erroneous and the old methods of testing sometimes gave far too large figures for the lime needs. Now with better methods of testing, we find that one application of lime may last for several rotations. In some of our experiments no further application has been found to be necessary for 16 years following the first.

THE FERTILIZER PROBLEM

There are too many individual problems under this heading to permit of any complete discussion of them. I shall merely refer to a few of the immediate and more pressing ones. In much of the Corn Belt the phosphates are still the chief fertilizers employed and much of the experimental data centers around the use of these materials We have found, for example, that the use of phosphates on most of our soils in Iowa brings about very beneficial effects, increasing the yields and improving the quality of the crops. However, we have not yet answered the question of which particular phosphate should be employed, or of the amount of the application or the time of application. While we have found in two recent dry years that phosphates may under such conditions do more harm than good and indeed actually decrease crop yields, it is undoubtedly true, on the other hand, that if more phosphate had been used this past season, we would not be facing such a bad situation in the matter of seed corn as seems to have developed.

There is also the question of the neutralizing effect of the phosphates on the acidity of the soil. We are not particularly concerned with this point for, as has been mentioned, the liming of acid soils is considered a fundamental treatment in all our soil management systems, and the use of phosphates is recommended to follow the proper supplying of organic matter and lime when necessary. Certainly there is little possibility of avoiding the liming operation on our acid

soils by using a phosphate, and hence it does not affect us to any great extent practically.

Then there are the complete commercial fertilizers and we know far too little about them and their action under Corn Belt conditions. We have been testing certain so-called standard brands, which is merely another name for most-used brands. The results are interesting and often very significant, sometimes not. It is certainly true that with a few exceptions, we do not know what formulas to use nor how much to apply to any of our soils. We put on an arbitrary amount or an amount supplying an equivalent amount of phosphorus to that in a phosphate tested on a corresponding area. Thus we obtain a comparison under those particular conditions as to amount and brand. But we need to go much further. One of our problems in the near future is going to be that of the proper use of complete fertilizers in the Corn Belt and it is tied up directly with land use planning. There is bound to be an increasing use of these materials and we need to know what ot use and how in order to permit of the best results and to avoid disappointments and difficulties. We have learned the danger of applying fertilizers in contact with the seed and the work of the Joint Committee on Fertilizer Application of the Society has done much to pave the way for a proper use of fertilizers.

There are many other fertilizer problems which are certain to arise in our land planning, but I have concentrated upon the most important and those most discussed at present.

THE EDUCATIONAL PROBLEM

Finally, there is, of course, the grave problem of bringing farmers to an understanding not only of the importance of land use planning for soil conservation and fertility maintenance but also of the methods necessary to bring about a proper and effective land use. The great problem here is how to overcome some of the difficulties incident to a change in cropping and farming systems and in methods of soil management. As I have suggested, these are extremely important, but since they involve economic and sociological considerations, I will not discuss them except to say that they may be very largely overcome by education. Farmers are alive to the dangers of erosion, they are beginning to recognize the depletion of the fertility of their land, and they are ready to do almost anything that is necessary. But we need to educate landlords, too, and that means the general public, and we need to see to it in some way that farm leases take into account the conservation of the land and are revised on sound agronomic principles. That will take some education of a great group of people who own land and whose only concern has been to get just as much income from it as possible. Hence, in the matter of leases, it is probable that legislation will be necessary along with education. The same is true of the tax problem. Some education is needed on this subject, but it is largely a legislative problem, after the legislators are educated.

THE IOWA FARM ADJUSTMENT STUDIES

The fact that many Iowa farmers are well up on the whole situation in connection with the adjustment program and the need for a sound land use program is indicated by the conference held last summer where the proposals coming out of the land use studies which I have described were discussed. The whole problem was considered in detail for several weeks by 25 farmers from various parts of the state, and after checking up on the conditions in their own counties, they came to the conclusion that there should be a differential reduction in corn acreage, averaging about 20%, the reduction being varied (a) between groups of counties according to the reduction that would be necessary to *maintain the present level of soil fertility*, and (b) between individual farms according to crop land in corn during the base years 1932–33.

The purpose of the program, they concluded, should be to direct the use of retired corn acres into grass instead of feed grains and they proposed to do this by establishing a grass base for the county and thus arrive at a percentage of grass land for each farm Then the contract signer to be in compliance must not only reduce the corn acreage as required but also show sufficient grass to at least equal the grass base.

THE GRASS LAND PROGRAM

The suggestion that benefit payments be made for land in grass rather than for land taken out of corn, or that the adjustment be put on a positive basis rather than on a negative basis, has been offered. This virtually amounts to paying the farmer to make adjustments in cropping systems which he has been urged to do in all our educational work out over the state for years in the interest of a permanent fertility of the soil. We have been recommending less corn and more legumes for keeping the land productive and for conserving it. We have been saying that it would pay and pay well in the long run Now there is considerable popular belief in the idea. The grass land program when adapted to long-time planning has much to recommend it in spite of all the arguments against it which may be brought up by the economists and those outside of the Corn Belt who are not so vitally concerned with the soil and its maintenance as we are.

It took a major depression and a cataclysmic disruption of the entire economic structure of the country to bring about an appreciation of the importance of proper land use and of soil conservation and especially to bring about some action to make them a reality. But these things have happened and we are now on the spot to furnish safe and sound agronomic plans for the proper use and preservation of our one great national asset—the land.

CULTURAL METHODS OF CONTROLLING WIND EROSION[1]

L. E. Call[2]

THE erosion of the soil by wind has occurred in the Central Plains states since their first settlement. When the territory was a cattle country, before general farming was practiced, wind erosion occurred around watering places, round-up grounds, and other places where the native vegetation was destroyed by trampling and the soil left in a comparatively smooth, bare condition.

As settlers broke out the native sod and placed the land under cultivation, wind erosion became more of a problem. Serious wind erosion was usually confined to isolated fields, however, and did not cause a difficult problem to more than the few individual farmers whose fields were affected. The first extensive area in Kansas to be seriously affected by wind erosion was in Thomas County. During a period of more than 3 years an area of approximately 65,000 acres northeast of Colby in Thomas County was blown disastrously. It was feared at the time that this area might become permanently a wind-blown desert of shifting dunes of silt. Drifts of soil buried fences, railroad tracks, groves of trees, and machinery, and surrounded farm buildings. Gentle breezes filled the air with dust that sifted into houses. Stronger winds moved banks of soil so that roads readily passable in the morning might be blocked by drifts of soil by evening, making travel extremely hazardous. The few rains that fell were ineffective and no crops were grown.

This condition resulted when a period of increasing agricultural prosperity during which many acres of native grass were brought under cultivation was followed by two extremely dry years, 1910 and 1911. The total precipitation for 1910 was 6.67 inches at Colby, the lowest on record. This extremely dry year was followed with only 10.55 inches of precipitation in 1911, which was at that time the third lowest on record There was a complete crop failure both seasons. In March 1912, a heavy snow fell. When the snow melted the soil was smooth and without the usual vegetative cover. It started to blow as soon as the surface dried. It continued to blow. With more than 20 inches of precipitation at Colby in 1912 and over 21 inches in 1913 blowing continued with increasing intensity and continued to spread over an ever-widening area. It reached the maximum intensity in the spring of 1914.

That spring a branch of the Kansas Agricultural Experiment Station was established near Colby on the edge of the district that was blowing. Steps were taken immediately to study methods of controlling blowing on the Station land. The lister was used and proved effective. An organization was then effected to protect the whole

[1]Contribution No. 55, Director's Office, Kansas Agricultural Experiment Station, Manhattan, Kan. Also presented before a joint meeting of the Society and Section O of the American Association for the Advancement of Science, St. Louis, Mo., December 31, 1935. Received for publication January 13, 1936.

[2]Director.

area that was blowing through the use of listers. Some strip listing was done, but before concerted action could be taken one of the most severe dust storms in the experience of the country occurred on April 23, 1914, completely obliterating nearly all of the listing that had been done. Following this setback a more carefully organized and directed attack was made upon the problem. Mr. J. B. Kuska, Associate Agronomist, Division of Dry Land Agriculture, U. S. Dept. of Agriculture, located at the Colby Station and who assisted with the control program, reports as follows in an unpublished manuscript written in 1934 upon the methods used and the success of the undertaking:

"A program was undertaken of listing solid, or every other row, or in strips as close as possible with the listers available and planting the land to corn or other row crops. The listing was done in an east to west direction. Much of the area was so handled. For a time it looked as though even these efforts might be unsuccessful. Whether or not the efforts would have been successful of themselves will always remain a question. At about this time nature came to the rescue. A rainy period set in after the first week in May, during which it rained nine out of eleven days. These showers brought up whatever had been planted, sprouted the weed seeds which were abundant everywhere, and kept the soil from blowing long enough to give the crops and weeds a chance to become established. . . . . There was an abundance of moisture in the soil, and, given a start, all vegetation made rank growth. Practically all this was left over winter as protection against possible blowing the following year.

"Nature having started the healing process appeared to be reluctant to turn the job over to man at this stage. The first nine months of 1915 the precipitation was above normal every month and the total for the year was 28.99 inches, only half inch below the all time record. . . . . That fall there was an abundance of moisture for fall wheat to start and make a good growth before winter set in. The following spring there were only a few bare fields, mostly fields where the wheat was sown too late to make enough growth to cover the ground. Most fields were covered with growing wheat, heavy stubble, corn or sorghum stalks, or weeds. High winds were frequent during the spring months, and many of the fields of late wheat blew out, but no extensive areas could blow because of the vegetation. The blowing fields were strip listed or otherwise worked to check the blowing in most cases, so that the blow district was farm land again.

"Since then, almost every spring with the exception of 1919, there has been some trouble experienced with wheat blowing out in this vicinity. At no time since, even in the years when wheat winterkilled, or during the driest years has there been any extensive area of uncontrolled soil blowing. Thousands of acres of winter wheat have been destroyed, but by the timely use of the lister and other precautionary measures, the land was saved from devastation."

The conditions that gave rise to the devastating dust storms and wind erosion throughout the Central Great Plains in the spring of 1934 and the spring of 1935 were similar to the conditions that preceded the destructive wind erosion at Colby from 1912 to 1914. The 4-year period, 1931 to 1934, inclusive, had been one of deficient rainfall throughout the Central Great Plains. Some of the precipitation records typical of the region illustrate the severity of the drouth. For example, at Dodge City, where the normal precipitation for a

period of 50 years has been 20.5 inches, there was an average of 15.9 inches for these 4 years, and with a total precipitation of only 11.5 inches in 1934. Furthermore, with a normal precipitation of 11.5 inches from July 1 to March 1, the precipitation from July 1, 1934, to March 1, 1935, was but 6.5 inches. At Colby, Kansas, the total precipitation for this period was but 3.9 inches as compared with a normal of 9.8 inches.

The lack of rain during the fall of 1934 made it impossible to secure stands of winter wheat over most of the territory and where there was sufficient moisture to start the crop a lack of precipitation during the winter months resulted in insufficient moisture to maintain it. Practically all fields that had been prepared for wheat were without a protective cover of vegetation when the strong spring winds started to blow in 1935. Furthermore, due to the drouth of 1934, there was a shortage of feed for livestock. Wheat stubble, corn and sorghum stalks, and Russian thistles and other weeds were harvested for feed or grazed off so closely that little or no crop cover was left on the fields. Even native buffalo grass pastures had been so heavily overgrazed that the soil on these fields was not adequately protected

Economic conditions combined with these favorable ecological conditions to accentuate the difficulty. Under normal economic conditions much land would be fall listed to protect it from blowing or in preparation for a spring crop. This year, however, the farmer's reresources were so exhausted following several years of crop failure that he did no more work than he thought absolutely necessary. He considered it advisable to conserve all available funds until time to plant a spring crop. Conditions were most favorable, therefore, for erosion when the wind started to blow in the spring of 1935.

This serious situation has been attributed by some to the rapid expansion in the area brought under cultivation during and immediately following the World War in response to the demand for increased food supplies. This was a major contributing factor only in some of the drier more sandy sections of the territory. In other sections this factor was important only in that it contributed to the extent of the area involved. Dust storms would have occurred and serious soil erosion would have taken place this past year if no additional land had been brought under cultivation during the war and post-war periods.

The condition that existed throughout the Central Plains territory was similar to the condition that had existed on a much smaller scale in the Colby territory 20 years earlier. With the experience at Colby as a guide an effort was made to perfect an organization in central and western Kansas where wind erosion was occurring and to take steps to stop it. District meetings were held in the affected territory attended by county agents, county drouth committeemen, and county commissioners to discuss the problem, consider methods that might be used and develop plans for making these methods effective. As a result a detailed survey of the condition of the land in each county was undertaken to determine the exact acreage that was eroding and in need of attention. The national Relief Administration

was asked to appropriate funds with which farmers might purchase fuel oil for tractors or feed for horses used in the work. An original allotment of $250,000 was made in Kansas for this purpose, which was later increased to about $328,000. This grant was made through allotments to counties based upon need as determined by the county survey and was distributed upon order from county poor commissioners to farmers who had been assigned areas to work and who had agreed to list or otherwise work the land in an approved manner to control blowing.

The survey showed that serious blowing was occurring in 47 of the 105 counties of Kansas, all located in the western and central parts of the state, and that the cultivated area in these counties exceeded 12 million acres of which over 8 million were in condition to erode from wind. This area in Kansas constituted less than half of the area comprising the so-called "dust bowl" which included parts of Oklahoma, Texas, New Mexico, Colorado, and Nebraska, as well as Kansas. Funds were granted from the Kansas Emergency Relief Corporation to farmers of the state to work 3,287,700 acres to control blowing. A report from county agents in those counties to which grants were made showed that at the close of the season 3,360,245 acres had been cultivated. The following report from Carl C Conger, County Agent of Kearny County, is typical of these reports.

Mr. Conger says, "On April 2, 1935, Kearny County was allocated gas and oil or feed for horses for the cultivation of 80,000 acres. This was about 40 per cent of the amount apparently needed. Additional allocations of 14,000 acres were granted this county on May 22, 1935. Farmers found the task of listing their land very difficult. Even though gas and oil for doing the work were made available, in the majority of cases the equipment to do the work was either not available or was not in condition to be used for such strenuous tasks. The frequency of the dust storms and the lack of funds prevented the farmers from making necessary repairs on their equipment. About one fourth of the area that was blowing was cultivated during the dust storms. Following the spring rains, however, a large part of the remaining land was cultivated immediately. A survey during June indicated that of those who had received allocations for soil blowing control, 94 per cent had their land under control."

The efforts of the farmers to control blowing were aided this season by rainfall somewhat above that of the previous 4 years This increased rainfall, together with various methods of cultivation that have been used to work the soil, have permitted weeds to start and crops to be planted which have re-established a cover of vegetation over much of the area in Kansas that was blowing last spring. Whereas it was estimated that 8 million acres were in condition to blow in March, 1935, a survey of the situation made the first of November showed this area to have been reduced to about 830,000 acres. Conditions in most of the other Central Plains states have improved also.

It should not be assumed from this statement that all danger of serious soil erosion by wind is past. There are areas remaining in Kansas that probably will require attention if blowing is to be avoided

next spring and conditions are also reported to be less satisfactory in some other states than in Kansas.

In the future, soil erosion by wind may be expected to become a serious problem whenever climatic conditions re-occur similar to the conditions that prevailed in Thomas County, Kansas, from 1911 to 1915 and throughout the Central Great Plains from 1931 to 1935. While conditions undoubtedly will re-occur which will require intelligent cooperative management of the land to control wind erosion, there is ample evidence available from the experience of the past to provide assurance that wind erosion may be controlled and that it should not be a major factor restricting the agriculture of this territory. Exception to this general statement should be made for certain comparatively small areas of sandy soil and perhaps portions of the more arid sections of the area that are now under cultivation. These areas should be taken out of cultivation and returned to grass or re-vegetated with some other crop cover.

To assist in understanding the cultural methods that should be practiced to control wind erosion, it may be desirable to describe in some detail the action of wind upon the soil. Prerequisite to any soil blowing is the presence of dry, partially deflocculated soil particles on the surface of a soil that is unprotected by vegetative cover. Under such conditions a strong wind will move the soil particles. At first only a few particles may be moved, but these particles sliding over the surface of the soil gradually disintegrate the soil granules producing an increasing number of soil particles of a proper size to be moved by the wind. While at first blowing is confined to a comparatively thin surface layer, the amount of soil that is moved gradually increases as blowing continues. Soil material that has blown remains in condition to be moved easily even under the impulse of moderate wind, thus the longer a soil is allowed to blow unchecked the more difficult it becomes to check it.

A small area of soil that starts to blow if unchecked constantly increases in size, involves a greater depth of soil and an enlarged area until it becomes a serious menace to all adjoining fields. Many fields protected with a vegetative cover sufficient to prevent the movement of the soil on the field itself may be started eroding by the encroachment of blowing soil from surrounding fields. When conditions favorable for blowing are long continued this encroachment of blowing soil may involve several farms, whole townships, or even counties where the areas consist largely of cultivated land. Under these conditions, which were common in the spring of 1935, control ceases to be an individual problem and becomes the concern of entire communities or even the county, the state, or the nation. The longer control measures are delayed, the more vigorous they must be and the greater the danger of permanent injury to the land. Control measures should be applied whenever possible before soil blowing actually starts. After blowing has developed over a large area, no amount of effort can stop it for more than a temporary period. The object of cultivation when blowing starts is to hold the soil in place until rains fall and vegetation starts. A vegetative cover is the only ultimate preventive of wind erosion.

While almost any soil will blow if in proper condition, the greatest difficulty of control is experienced with sandy types. The particles of a sandy soil exist as individuals or break down easily from a granulated state into individual particles of the size easily moved by wind. Sandy soil also contains less cementing material that tends to hold the particles in place or binds them together. The more rounded shape of the sand particles may cause them to move easier under the action of the wind and their greater weight may result in greater abrasive action. Because of the ease with which sandy soils erode by wind, it is exceedingly difficult after blowing starts to control it by cultivation. The lighter types of sandy soil should not be brought under cultivation under semi-arid conditions and such soils that are in cultivation should, under most circumstances, be re-vegetated. Sandy soils of a somewhat heavier character may be cultivated successfully if handled in such a manner as to keep them covered with vegetation or crop residue during the seasons of the year when blowing occurs.

The soil conditions most favorable for blowing are a smooth, finely pulverized surface free from a growing crop, weeds, or crop residue. A soil in the best condition to resist blowing is one that is covered with growing vegetation, weeds, or crop residue, or if without vegetative cover, one that is rough and cloddy.

In the Central Great Plains the cultural methods that should be employed to control blowing may be classified in three categories as follows: (1) the cultural methods used during the summer and fall tillage period prior to the winter and spring months when strong winds usually occur, (2) cultural methods used on land that is in condition to blow but has not actually started to erode, and (3) cultural methods that may be employed to stop soil blowing after it has started.

Summer-fallowed land is an example of the type of land that usually requires cultural treatment of the kind falling under the first category. The soil-blowing hazard on summer-fallowed land may be reduced by doing no more tillage work than is absolutely essential to control weed growth, to cultivate if possible only when the ground is moist, and to use types of tillage tools that do not pulverize the soil. Such tools as as the spike-tooth harrow, tandum disk, and under most conditions the "one-way" should not be used since they pulverize and level the ground and leave it in condition favorable for blowing. Instead of using implements of this character it is desirable to use clod-raising or furrow-making tools that leave the surface of the soil cloddy and rough and at the same time destroy weeds. The most satisfactory tillage tools of this character are the rod weeder and shovel cultivators of all types, such as the spring tooth harrow and "duckfoot" or field cultivator.

Land tilled with these implements will be left in as good condition to resist blowing as is practicable when a complete summer fallow system is followed. When summer-fallowed land is carried over for a spring crop, it usually falls into the second category of the above classification, that is land in condition to blow. In addition to fallow, any other land upon which no crop is grown through failure to secure

a stand would fall in this classification. Other land of this character is fall-plowed ground, especially if the ground did not turn up in lumps, or if freezing and thawing during winter slakes down the clods. Corn and sorghum stubble from which the stalks are cut sufficiently high will usually protect the soil from blowing. Land left over winter in grain stubble or with a cover of weeds will not blow and winter wheat that makes a good fall growth usually protects the soil successfully.

Any land in the Central Great Plains that is not protected by a cover of vegetation will blow in the spring if winter conditions have been such that the surface soil granules are broken down by freezing and thawing during winter and if the spring is dry and windy, as is usual in this territory. This applies to corn and sorghum land from which the crop has been harvested, wheat fields unprotected by green growth or stubble, fall-plowed land, and other unprotected land of this character. Such land should be worked in the early spring to protect it. It may be worked with a spring tooth or "duckfoot" cultivator or with any other tillage tool that will roughen the surface of the soil. When a field of wheat has survived the winter but has not made sufficient growth to protect the soil the field may be cultivated with a "duckfoot" type cultivator with the "duckfoot" shovels replaced with the ordinary cultivator type shovel. If these shovels are placed 24 to 36 inches apart they will not destroy a large percentage of the wheat plants and the soil will be roughened sufficiently to protect the field against erosion under ordinary conditions. Under extreme conditions the lister must be used.

When land reaches the condition described in the third classification and erosion of the soil has started, prompt and effective cultural methods must be used to stop it. It is more difficult to stop soil blowing after it has started than to prevent it before it actually occurs. When the soil has started to blow one of two things must be done to stop it, either some protective covering must be applied to the soil or some sort of obstruction erected to check and lift the wind current above the surface soil. Except on small exposed hill tops, where erosion frequently starts and which may be protected by applications of straw, coarse manure, or some other kind of organic matter, the first method is impractical.

The second method may be successfully employed by using the soil to erect the barriers. This may be accomplished by using any tillage implement that roughens the surface and leaves it furrowed. The clods that are brought to the surface and the furrows form the windbreaks that check the force of the wind and catch and hold the drifting soil. The greater the capacity of the furrows for holding the drifting soil, the more effective the method. Thus, the more cloddy and furrowed its surface, the more permanent the results. Any shovel-type implement may prove successful if the ground is moist and drifting has not progressed far, but under extreme conditions the lister is the most effective tool to use, since the furrows left by the lister are deep and have the maximum capacity for holding drifting soil.

Under extremely dry conditions when cloddy soil cannot be brought

to the surface with a lister, the chisel cultivator may sometimes be used effectively on heavy soils.

Another implement that has been used successfully to roughen dry hard ground is the so-called "wide-spaced one-way". This implement is made by removing all but every fourth or fifth disk on an ordinary one-way disk. This implement has not only proved effective when used on hard ground but has been economical to operate. It may be used on land too hard and dry to work with a lister.

When soil and climatic conditions are favorable for wind erosion, all cultural methods must be considered as temporary. Cultivation cannot stop soil blowing permanently, but proper methods of tillage can delay destructive action of the wind for long periods of time. Severe drouth is always associated with conditions favorable for soil blowing and if drouth conditions prevail a sufficient length of time they will overcome any plan of cultural treatment that may be devised to protect the soil. Tillage must be considered therefore as a temporary method to hold the soil until rain falls. Rain will supply the moisture necessary for vegetation to start. A cover of vegetation is absolutely essential if the soil is to be removed from a potentially dangerous condition from the standpoint of wind erosion

Rain alone, falling on land that has been blowing, will not afford the condition necessary for vegetation to start unless followed by a period of several weeks with low wind movement. The surface soil of a field that has blown will be in condition to blow again as soon as it becomes dry. The movement of the soil will destroy any small plants that start following the rain. It is necessary therefore to cultivate the soil after a rain to break up the smooth surface in order that soil movement will be stopped long enough to enable plant growth to start. After growing vegetation reaches a height sufficient to protect the surface soil the danger of wind erosion is passed as long as the cover of vegetation remains on the field.

The following rules if adhered to should prevent disastrous wind erosion in the Central Great Plains:

1. Keep the soil covered with growing vegetation or crop residue as much of the time as possible, consistent with good soil and crop management.

2. Avoid as far as possible working the soil when it is dry.

3. Take precautionary cultural measures to protect the soil against wind erosion before it occurs and if blowing starts take prompt action to stop it.

4. Restrict cultivation for the control of wind erosion to the amount needed to obtain the necessary control.

5. Use implements for cultivation of a type that leave the surface soil rough and ridged rather than smooth and level.

6. Take advantage of any rains that fall to cultivate the soil in a manner to hold it from blowing until a growth of vegetation starts to protect the soil.

7. Re-establish permanent vegetation on areas of soil so sandy, so arid, or so impervious to water that the control of wind erosion is extremely difficult. Such areas constitute but a small portion of the cultivated land in the Central Great Plains.

Where precautionary measures such as these have been taken, destructive wind erosion has been prevented throughout most of the Central Great Plains. There is no reason to expect that wind erosion will not be controlled in this region unless climatic conditions occur that are much less favorable for the growth of vegetation than those that have prevailed during the past 50 years. The best information available would lead to the conclusion that while periods of serious wind erosion will occur in the future during times of drouth, such periods will not lead to the destruction of the soil or become a major factor that will preclude the utilization of this area for successful crop production.

THE EFFECTS OF 12-YEAR RESIDUES OF LIME AND MAGNESIA UPON THE OUTGO OF SUBSEQUENT ADDITIONS OF POTASH[1]

W. H. MacIntire, W. M. Shaw, J. B. Young, and B. Robinson[2]

The literature relating to calcium-potassium relationships in soil systems is extensive. The subject has been attacked from several angles. When unlimed soil is agitated in water and in a neutral solution of a calcium salt, the filtrate from the latter generally shows the higher content of potassium. From this it has been deduced that incorporations of liming materials will result in a liberation of soil potassium. On the other hand, the potassium content of the rain-water leachings from an acid soil will be greater than the potassium content of the leachings from the same soil limed. As a corollary, the potassium content of the ash of a plant grown on an acid soil will exceed the potassium content of the ash of the same plant grown on that soil after full-depth liming. The two latter methods of attack furnished data that warrant the conclusion that lime does not effect a liberation of soil potash.

The literature on the subject has been presented in several previous publications from the Tennessee Experiment Station, all of which were cited in the last contribution on the subject in 1930 (4).[3] Since that time additional contributions have been made by Jenny and Shade (1), Lamb (2), Peech and Bradfield (7), Sewell and Latshaw (8), and Snyder (10), and in a joint study from the Virginia and Tennessee Experiment Stations (6).

In the several contributions from the Tenessee Station the influence of calcic and magnesic additions upon the solubility of soil potash has been measured by the outgo of potassium from native supplies and from simultaneous incorporations of potash and liming materials. The present contribution deals with the effects induced by 12-year residues of calcic and magnesic materials upon the fate of the potassium supplied by six subsequent annual additions of potassium sulfate, as measured by the content of rainwater leachings from outdoor lysimeters.

EXPERIMENTAL

At the end of a 12-year period after single full-depth incorporations of the several liming materials, during which time a detailed record of outgo of Ca, Mg, K, and SO_4 was obtained, annual applications of potassium sulfate solutions were made uniformly to the surface of the soils in 1/20,000th-acre lysimeters, at the constant rate of 270 pounds of K_2SO_4 (200 pounds K_2O, 166 pounds K) per 2,000,000 pounds of soil. The soil was not disturbed during the 12-year period subsequent to the incorporation of the liming materials, nor during the succeed-

[1]A contribution from the Department of Chemistry, University of Tennessee Agricultural Experiment Station, Knoxville, Tenn. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 6, 1935.

[2]Head of Department, Associate, and Assistant Soil Chemists, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 214.

ing 6-year period. The soil was a brown clay loam of a slightly sandy phase and of moderate fertility. It contained 0.93% total K and 0.009% exchangeable K, as determined by extraction with boiling N/1 ammonium chloride (9), and showing a hydrogen electrode pH value of 6.27.

The initial and single liming treatments were divided into four series. In one series of six units, the unsupplemented additions of limestone, dolomite, burnt lime, and magnesia were at the equivalent rate of 1 ton of CaO per 2,000,000 pounds of soil and the oxides of calcium and magnesium were also used at the rate of 3,750 pounds CaO≈. In the other three series of five units each, sulfur was added in one of the three forms of ferrous sulfate, pyrite, and flowers of sulfur at the constant rate of 1,000 pounds of S. The lime and equivalent MgO supplements in these three series were at the two rates of 3,750 pounds and 32 tons CaO-equivalence, respectively. Used jointly with sulfur, the 3,750-pound additions represented a 1-ton equivalent rate of CaO, plus the immediate and also the potential acidity of the sulfureous materials. All of the additions of liming materials and of sulfur were mixed throughout the soil at the beginning of the experiment in August, 1917. The first of the surface additions of the dissolved K_2SO_4 was made in August, 1929, with repetitions each year thereafter.

OUTGO OF K SUBSEQUENT TO ADDITIONS OF K_2SO_4

In considering the effects of the residues of the several liming materials upon the fate of added potassium, it should be noted that each and every form and rate of lime and magnesia had caused a decrease in the outgo of K derived from the natural supplies of potassium during the 12-year period that preceded the 6-year period of the present experiment. In those control units where the three forms of sulfur were used without liming supplements, the outgo of K was slightly greater than the outgo from the untreated soil. The sulfur additions were equivalent to $CaSO_4$ at the rate of 4,250 pounds per 2,000,000 pounds of soil, but the enhancements in K outgo were but a mere fraction of the exchange equivalent of that amount.

The outgo of K from each treatment and the concentrations of the K in the leachings for each annual period, 1929–1935, inclusive, are shown in Table 1. The averaged leachings of K, as averages for the several rates of liming materials and the sulfur supplements for the first 12-year period and for the last 6-year period, are given in Figs. 1 and 2, respectively.

There occurred an immediate increase in the outgo of K from each of the unlimed group controls. This acceleration in K outgo from the units that had been rendered more acid than the untreated soil by the additions of the sulfureous materials was distinctly greater than that shown by the soil that received only K_2SO_4. The decided increase in K outgo from the additions of K_2SO_4 to the unlimed control soil did not appear until the third year. A reverse effect was noted for the calcium and magnesium residues in 16 of the 18 limed units during the first two years. During the third annual period the outgo of K from each of the 18 limed units was decidedly greater than the amounts of K leached during previous years, but the repressive effect of the residues of CaO and of MgO were marked in the case of 14 of the 17 units, exclusive of the 3 units that received MgO at the 32-ton rate. A marked enhancement in K outgo from

TABLE 1.—*Outgo of K from a clay loam treated with calcic and magnesic materials alone and with three forms of sulfur as measured by lysimeter annual leachings during a 6-year period subsequent to additions of 200 pounds of K_2O per acre* per annum.*

No.	Treatment	K, lbs. per acre* per annum								Concentration of leachates, p.p.m.						Concentration of K in leachings p.p.m.	
		1929–30	1930–31	1931–32	1932–33	1933–34	1934–35	Total	Variation	1929–30	1930–31	1931–32	1932–33	1933–34	1934–35	Average	Variation from control
50	None	16.6	9.0	50.6	96.7	90.0	163.9	426.8	—	3.33	2.40	8.40	13.50	18.80	25.80	12.90	—
51	Limestone	16.2	10.1	51.0	83.7	92.3	147.1	400.4	—26.4	3.19	2.48	8.00	11.00	17.60	21.40	11.37	—1.53
52	Dolomite	16.7	13.3	40.7	64.5	85.3	144.3	364.8	—62.0	3.29	3.28	6.30	8.50	16.40	21.40	10.38	—2.52
53	CaO, 1 ton	15.3	7.1	40.0	64.0	87.1	120.2	333.7	—93.1	3.05	1.88	6.40	8.30	15.60	17.60	9.54	—3.36
54	CaO, 1 ⅞ tons	13.8	4.0	21.2	59.9	74.7	111.9	285.5	—141.3	2.77	1.13	3.50	8.40	15.20	17.20	8.63	—4.27
55	MgO, 1 ton	14.5	8.4	39.1	66.9	77.5	121.3	327.7	— 99.1	2.86	2.28	6.30	9.20	15.20	18.00	9.62	—3.28
56	MgO, 1 ⅞ ton	5.8	2.3	22.3	56.0	71.5	95.9	253.8	—173.0	1.14	0.63	3.60	7.60	14.00	14.20	7.43	—5.47
57	$FeSO_4$ alone	25.1	21.4	95.1	131.8	103.9	155.9	533.2	+106.4	5.12	6.25	16.70	18.50	22.40	24.80	16.62	+3.72
58	$FeSO_4$+1 ton CaO	9.2	3.3	29.9	74.7	98.7	127.8	343.6	— 83.2	1.88	0.95	5.00	10.40	19.60	20.00	10.43	—2.47
59	$FeSO_4$+1 ton MgO	7.3	2.8	28.9	55.9	80.9	130.5	306.3	—120.5	1.53	0.83	5.00	8.00	15.60	20.40	9.41	—3.49
60	$FeSO_4$+32 tons CaO	13.7	6.1	24.4	59.0	69.9	118.9	292.0	—134.8	2.91	1.88	4.30	9.00	15.20	20.40	9.54	—3.36
61	$FeSO_4$+32 tons MgO	15.6	9.0	90.0	158.0	127.7	176.8	577.1	+150.3	3.74	3.53	17.20	25.20	31.20	35.00	21.08	+8.18
62	Pyrite alone	20.6	21.5	86.5	117.3	93.9	165.8	505.6	+ 78.8	4.28	6.55	15.10	19.80	24.80	26.80	17.02	+4.12
63	Pyrite+1 ton CaO	10.6	2.2	20.6	56.8	71.6	130.9	292.7	—134.1	2.21	0.63	3.40	8.80	14.80	20.80	9.18	—3.72
64	Pyrite+1 ton MgO	8.6	4.5	23.7	51.2	79.0	137.1	304.1	—122.7	1.76	1.25	3.80	7.00	15.60	20.00	8.95	—3.95
65	Pyrite+32 tons CaO	11.7	4.5	7.5	45.6	69.8	115.2	254.3	—172.5	2.71	1.53	1.40	7.00	15.60	20.40	8.70	—4.20
66	Pyrite+32 tons MgO	7.6	9.0	75.7	123.7	144.4	171.1	531.5	+104.7	1.78	3.38	14.70	19.80	34.80	33.00	19.24	+6.34
67	Elemental S alone	20.3	14.7	83.8	106.6	102.7	140.5	468.6	+ 41.8	4.24	4.30	14.90	14.80	22.40	22.20	14.67	+1.77
68	Elemental S+1 ton CaO	11.3	1.5	25.8	57.4	72.5	122.9	291.4	—135.4	2.39	0.45	4.30	8.00	15.20	19.60	9.02	—3.88
69	Elemental S+1 ton MgO	9.3	1.7	18.2	40.5	71.9	132.6	274.2	—152.6	1.98	0.50	3.00	5.60	14.80	21.20	8.41	—4.49
70	Elemental S+32 tons CaO	9.0	4.2	11.4	51.1	61.0	106.3	243.0	—183.8	2.13	1.33	2.10	7.70	14.00	18.20	8.23	—4.67
71	Elemental S+32 tons MgO	6.9	5.1	72.8	138.3	133.8	161.8	518.7	+ 91.9	1.67	1.90	14.20	22.60	33.20	31.00	19.02	+6.12
	Rainfall, inches	46.0	42.5	51.8	62.0	49.0	57.5	308.8									

*2,000,000 pounds of soil.

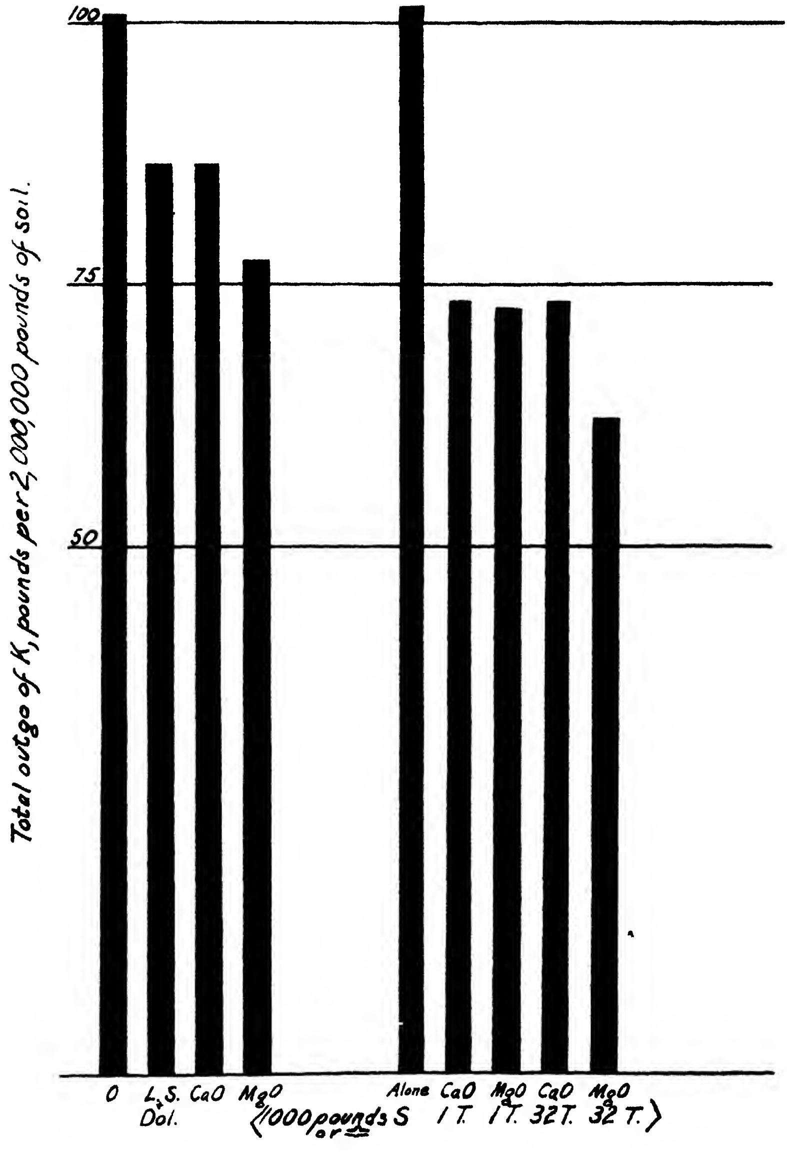

FIG. 1.—Influence of additions of calcic and magnesic materials, alone and with sulfur, upon solubility of native supplies of soil potassium as measured by outgo of K from a brown clay loam during a 12-year period. Averages for limestone-dolomite at the 1-ton CaO-equivalent rate; both CaO and MgO at 1-ton and 1⅞-ton rate; CaO at 1⅞-ton rate with supplements of $FeSO_4$, pyrite, and sulfur at the rate of 1,000 pounds S, and the same for 1⅞-ton CaO-equivalence of MgO; CaO and also MgO at the 32-ton CaO-equivalent rate with the three sulfur supplements.

all units was registered during the third year, and excepting the delayed effect for the 32-ton CaO treatments, each outgo for the third year was in excess of the corresponding total for the first 2 years. Consistently, however, the residues from all calcic treatments in-

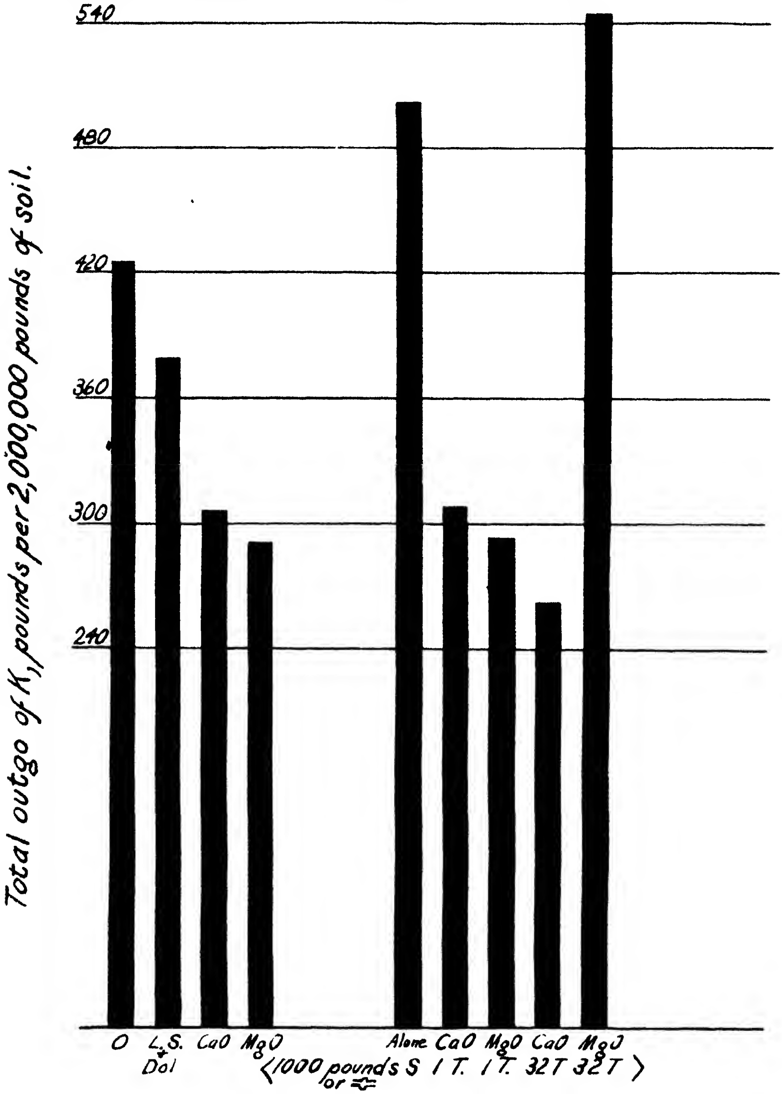

FIG. 2.—Influence of residues from additions of calcic and magnesic materials, alone and with supplements of sulfur, to a brown clay loam, as in Fig. 1, upon retention of K from K_2SO_4 additions—annual additions of K at the rate of 370 pounds K_2SO_4 (200 pounds K_2O, 166 pounds K) 13th–18th years, inclusive.

duced a decrease in the outgo of K below the amount that passed from the several unlimed controls. This repressive effect of the several liming materials was in continued evidence during the 6-year period for all treatments of the first, or no-sulfur, group, the maximal effects being the minus aggregate value of 173 pounds for the residues from the 1⅞-ton MgO treatment. The recovery from the additions to the previously untreated soil was 569 pounds short of the 996-pound addition of K, whereas the average of outgo totals for the six residues of the first group was 668 pounds. This means that the average repressive effect exerted by the six liming treatments was 99 pounds of K for the 6-year period.

In the three series that received the sulfur supplements in 1917, along with the liming treatments, the residues from the 32-ton CaO additions prevented a marked increase in outgo of K until after the third year. It was during this period, however, that a markedly divergent effect was induced by the residues from the 32-ton additions of MgO. This signal and sole divergence for units 61, 66, and 71 of the last three groups continued during the last 4 years.

The averaged cumulative effects induced by the several liming materials during the 6-year period are shown in Figs. 3 and 4 in which the results for the comparable or identical liming treatments, with and without sulfur supplements, are grouped. In both figures

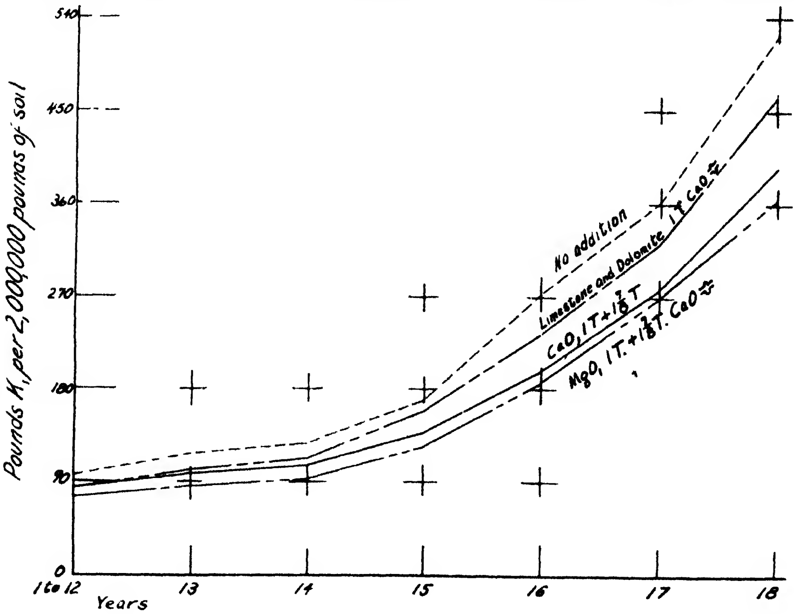

FIG. 3.—Cumulative outgo of K from a brown clay loam that received six annual additions of K_2SO_4 at rate of 370 pounds (200 pounds K_2O, 166 pounds K), as influenced by residues from limestone-dolomite, CaO, and MgO added 12 years before first addition of K_2SO_4. Limestone and dolomite, 1-ton CaO-equivalence averaged; CaO, 1-ton and 1⅞-ton averaged; MgO, 1-ton and 1⅞-ton CaO-equivalence averaged.

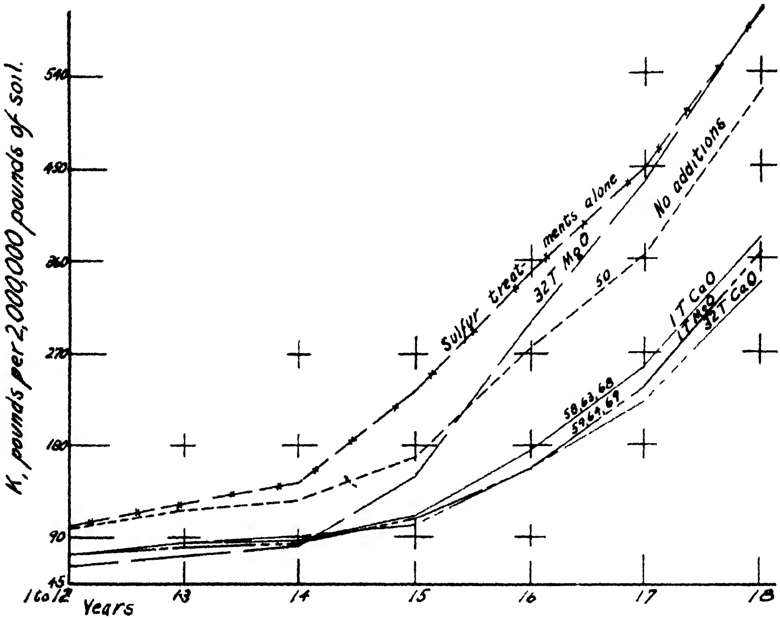

FIG. 4.—Cumulative outgo of K from a brown clay loam that received six annual additions of K_2SO_4 at rate of 370 pounds (200 pounds K_2O, 166 pounds K) as influenced by residues from incorporations of CaO and MgO and 1000 pounds of S, in three forms, that had been made 12 years before the first addition of K_2SO_4. Averages for CaO at 1⅞-ton and 32-ton rates, with constant supplement of sulfur in forms of $FeSO_4$, pyrite, and S. Averages for MgO at 1⅞-ton and 32-ton equivalent rates, with constant supplements of sulfur in forms of $FeSO_4$, pyrite, and S.

the starting points are the termini of the cumulative curves previously obtained for the first 12-year period during which no additions of potassium had been made. The variations in totals and in concentrations shown in the last column in the two sections of Table 1 warrant conclusions which may be summarized as follows: An increase in acidity—in parallel with a marked increase in outgo of native supplies of Ca + Mg (Table 2)—caused the unlimed controls to yield more K, or to fix less, than in the case of the soil that received no treatment save the six additions of K_2SO_4. The residue from each and every addition of limestone and of dolomite and of CaO at the three rates, 1 ton, 1⅞ ton, and 32 tons, caused a fixation of K greater than that induced by the unlimed soil. The same repressive effect upon outgo was registered by the smaller residues from the lighter treatments of MgO at the CaO ≈ rates of 1 ton and 1⅞ tons. These two statements as to the fixing power exerted by the all residues of CaO and the light residues of MgO are true for the liming materials alone and also with the supplements of the three forms of sulfur. After the third addition of K_2SO_4, however, the residues from the 32-ton additions of MgO registered an effect opposite to that registered upon K outgo from native supplies dur-

ing the first 12 years before the K_2SO_4 additions and also subsequent to the first two annual additions. The final result was a distinct acceleration and a marked enhancement in outgo of K. The maximal values for final annual concentration and total outgo of K was registered by the 32-ton MgO incorporations.

RELATION OF Ca + Mg OUTGO AND CONCENTRATIONS TO THOSE OF K

It is pertinent to compare the amounts of the alkaline earths and of K leached during the initial 12-year period with the corresponding values found for the subsequent period of 6 years. A similar comparison for the concentrations of Ca + Mg and K in the leachings obtained during the 12-year and 6-year periods is likewise germane. It has been pointed out (3) that the leachings from CaO additions to this type of soil will show a decrease in outgo of magnesium and that MgO additions will cause a decrease in the outgo of calcium. Table 2 gives the combined Ca + Mg values in terms of $CaCO_3$ for rainwater increments, for total outgo, and also for concentration in the leachings for the 12-year period and for the succeeding 6-year period in juxtaposition to the corresponding K values. The averaged concentrations of Ca + Mg in the leachings from the different liming materials are shown graphically for the two periods of 12 and 6 years in Fig. 5. Corresponding concentration values for the K content of leachings for the same two periods are shown in Fig. 6.

In the no-sulfur series the average concentration of Ca + Mg was 60.5 p.p.m. $CaCO_3$-equivalence during the first 12-year period and 61 p.p.m. for the following 6 years, with respective average annual rainfalls of 51 and 51.5 inches. The average annual increment of Ca + Mg from rainwaters was 79 pounds per acre surface for the first 12 years and 112 pounds for the last 6-year period. The replacement of Ca and Mg by the K of the added K_2SO_4 and the larger quantity of Ca + Mg derived from rainwaters during the last 6 years tended to maintain the outgo of the alkaline earths from the no-sulfur group. Since each of the unlimed sulfur-treatment controls had suffered a marked depletion in native bases because of the enhanced outgo of Ca and Mg as sulfates, especially during the early years of the 12-year period, a decrease in the Ca + Mg outgo from these units during the last 6-year period was inevitable. This sulfate effect from the sulfur additions—equivalent to 4,250 pounds of $CaSO_4$, or 3,125 pounds of $CaCO_3$—was evidenced by the immediate increase in outgo of SO_4 induced by $FeSO_4$ and the protracted effect induced by the sulfofication of the oxidizable materials, pyrite and elemental S (5), was also apparent in the concentrations of Ca + Mg in the leachings from the light additions of CaO and MgO during the final 6 years. For that period the Ca + Mg concentrations in the leachings from the light additions were practically the same, irrespective of the sulfur supplements. The SO_4 outgo was determined for each of the 18 annual periods, but the results are not essential in the present discussion and they will not be given.

The main cause for the ultimate decrease in the outgo of Ca + Mg from the 32-ton units was the large outgo of Ca from the initial CaO

TABLE 2.—*Total and average annual outgo of Ca + Mg and K and their concentrations in the leachings from a clay loam during a 12-year period subsequent to additions of calcic and magnesic materials, and during a subsequent 6-year period of annual additions of 200 pounds of K_2O per acre.**

No.	Treatment	Ca + Mg outgo as $CaCO_3$						Potassium outgo as K					
		Lbs. per 2,000,000 lbs. of soil				Concentration, p.p.m.		Lbs. per 2,000,000 lbs. soil				Concentration, p.p.m.	
		Total		Av. annual				Total		Av. annual			
		First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.
50	None	3,257	1,640	271	273	44.4	49.5	101	427	8.4	71.2	1.37	12.90
51	Limestone	3,712	1,988	309	331	50.3	55.6	95	400	7.9	66.7	1.30	11.37
52	Dolomite	3,934	2,073	328	346	52.9	59.0	79	365	6.6	60.8	1.07	10.38
53	CaO, 1 ton	3,892	1,961	324	327	53.6	55.8	87	334	7.3	55.7	1.20	9.54
54	CaO, 1 7/8 ton	5,040	2,229	420	372	71.5	67.4	87	286	7.3	47.7	1.24	8.63
55	MgO, 1 ton	4,130	2,118	344	356	57.7	62.1	73	328	6.1	54.7	1.02	9.62
56	MgO, 1 7/8 ton	5,551	2,258	463	376	76.8	66.1	83	254	6.9	42.3	1.15	7.43
57	$FeSO_4$ alone	4,907	1,249	409	208	71.1	39.0	99	533	8.3	88.8	1.44	16.62
58	$FeSO_4$ + 1 ton CaO	6,577	2,025	548	338	94.6	61.5	74	344	6.2	57.7	1.06	10.43
59	$FeSO_4$ + 1 ton MgO	7,104	1,958	592	326	103.8	60.1	79	306	6.6	51.0	1.15	9.41
60	$FeSO_4$ + 32 tons CaO	15,724	5,159	1,310	860	259.8	168.7	77	292	6.4	48.7	1.26	9.54
61	$FeSO_4$ + 32 tons MgO	28,137	6,244	2,345	1,041	478.0	228.0	69	577	5.8	96.2	1.17	21.08
62	Pyrite alone	5,175	1,303	431	217	74.8	43.9	102	506	8.5	84.3	1.46	17.02
63	Pyrite + 1 ton CaO	6,479	2,279	540	380	92.1	71.5	71	293	5.9	48.8	1.01	9.18
64	Pyrite + 1 ton MgO	6,555	2,340	546	390	91.3	68.9	67	304	5.6	50.7	.93	8.95
65	Pyrite + 32 tons CaO	17,981	5,172	1,498	862	283.6	176.9	70	254	5.8	42.3	1.11	8.70
66	Pyrite + 32 tons MgO	23,649	6,093	2,387	1,016	473.1	220.6	61	532	5.1	88.7	1.00	19.24
67	Elemental S alone	5,071	1,303	423	217	71.9	40.8	105	469	8.8	78.2	1.49	14.67
68	Elemental S + 1 ton CaO	6,398	2,045	533	341	92.0	63.3	77	291	6.4	48.5	1.11	9.02
69	Elemental S + 1 ton MgO	7,563	2,063	630	344	107.4	63.3	74	274	6.2	45.7	1.05	8.41
70	Elemental S + 32 tons CaO	17,693	5,375	1,474	896	269.5	181.9	75	243	6.3	40.5	1.15	8.23
71	Elemental S + 32 tons MgO	29,7[illegible]	6,044	2,477	1,007	498.7	221.6	59	519	4.9	86.5	1.00	19.02
	Rainfall, inches	[illegible]1.8 ([illegible]8)†	308.8 (670)†	51.0 (79)†	51.5 (112)†			611.8	308.8	51.0	51.5		

*2,000,000 pounds of soil.
†Values in brackets represent increments of Ca + Mg from rainwaters.

treatments and the still larger Mg outgo from the more soluble MgO (during and after carbonation) treatments with the consequential decrease in residues. But the diminution in Ca + Mg concentrations during the last 6 years cannot be utilized to explain the fact that initially the heavy MgO treatments registered a decidedly repressive

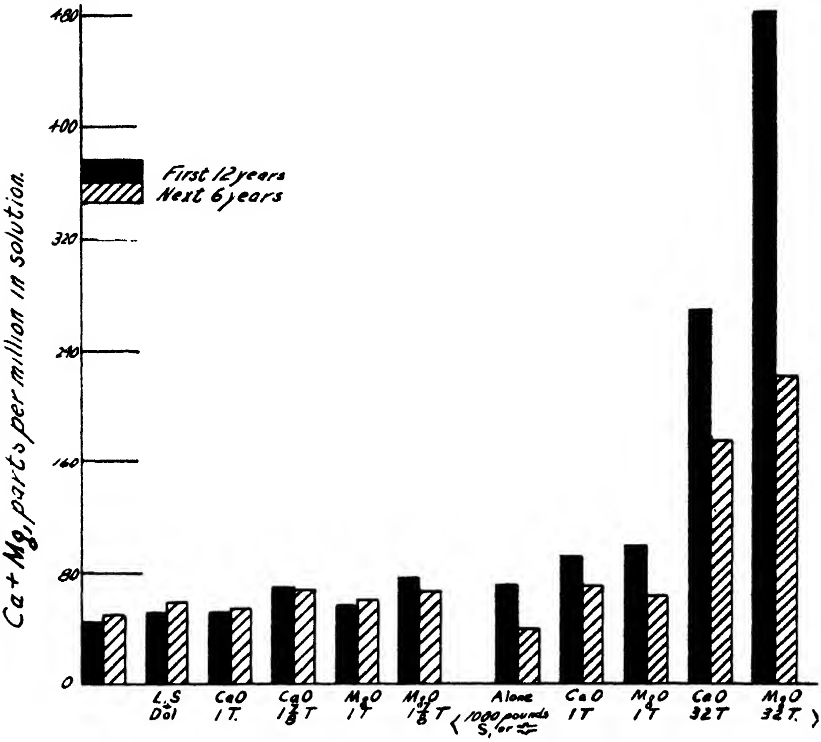

FIG. 5.—Average concentrations of Ca + Mg as p. p. m. $CaCO_3$-equivalents in the rainwater leachings from a brown clay loam during the first 12-year period after additions of calcic and magnesic materials, alone and with three forms of sulfur, in comparison with the average concentrations during the succeeding 6 years of annual additions of K_2SO_4 at the rate of 370 pounds per 2,000,000 pounds of soil.

effect and later an accelerative effect upon outgo of K, since the Ca + Mg concentrations of from 60 to 70 p.p.m. $CaCO_3$ equivalence from the light additions of both CaO and MgO showed a decided fixation of K, or a decrease in the outgo of that element. With a considerable drop from the 12-year average of 271 p. p. m. Ca + Mg concentration for the heavy CaO additions to the 175 p. p. m. average for the same additions during the last 6 years, the repressive effect upon K outgo was still in evidence. The Ca + Mg concentration values for the 32-ton MgO units, 61, 66, and 71, during the last 6 years, were less than the corresponding concentrations shown by these heavy treatments during the first 12 years, but they were still materially greater (27%) than the Ca + Mg concentrations found for the leach-

ings from 32-ton CaO units. Nevertheless, the MgO units, 61, 66, and 71, show an ultimate effect the reverse of that shown by the heavy or 32-ton, CaO units, *viz.*, 60, 65, and 70.

Although the reversal in the initial effect induced by the heavy additions of MgO did not appear until after the beginning of the third

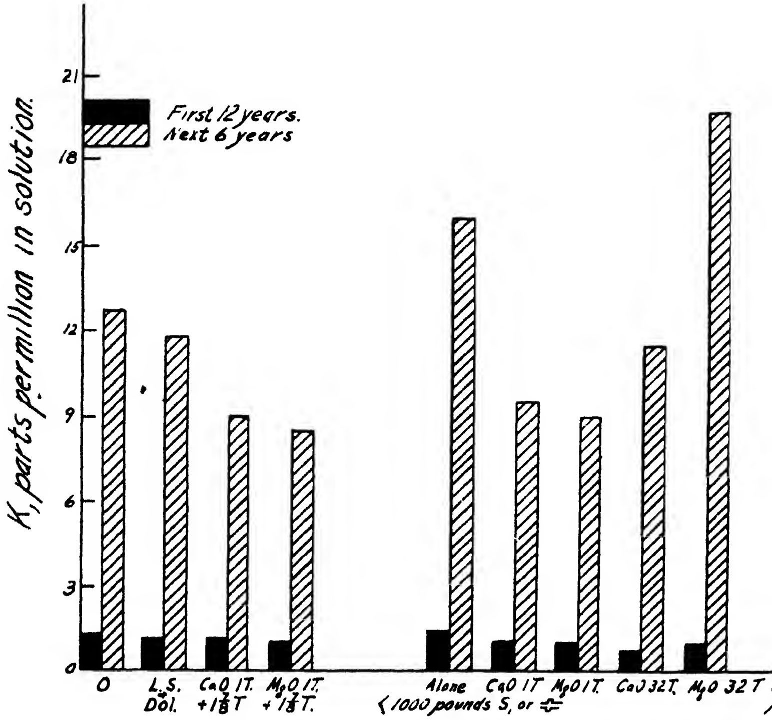

FIG. 6.—Average concentration of potassium as p. p. m. K in the rainwater leachings from a brown clay loam during the first 12-year period after additions of calcic and magnesic materials, alone and with three forms of sulfur, in comparison with the average concentrations during the succeeding 6 years of annual additions of K_2SO_4 at the rate of 370 pounds per 2,000,000 pounds of soil.

annual addition of K_2SO_4, the final accelerative effect during the last 4 years was so marked as to offset the initial repressive effect. The average concentration of K in the leachings from the 32-ton MgO units was 19.8 p. p. m. This was 6.8 p. p. m. greater than the concentration found for the untreated soil and 3.7 p. p. m. greater than the K value obtained for the leachings from the units that had become more acid and base-depleted, because of the additions of the three forms of sulfur. The unabsorbed residues of the CaO additions are known to have been converted completely to $CaCO_3$ and the unabsorbed residues of MgO had been converted to $Mg(OH)_2$ and in part to $3MgCO_3.Mg(OH)_2$ more than 10 years before the beginning of the last 6-year period during which annual additions of K_2SO_4 were made.

It is evident, therefore, that (a) initially, a low concentration of K was made still lower in the free soil water of a soil system of marked alkalinity and the corollary, the same alkaline soil system effected a marked fixation of added K and (b) subsequently (after one more addition), with an increase in concentration of K induced by further additions of K_2SO_4, there was less fixation of K by exchange between the build-up of Mg than between the added K and the build-up of H in the base-depleted control soil. This was true also for the still more acid sulfur-treatment controls.

It is difficult to explain why a soil saturated with Mg during a 12-year period of exposed contact with an excess of alkaline forms of magnesium could effect a fixation of K greater than that effected by a more acid system of the same soil, when the soil system was "bathed" with a low concentration of potassic salts, and then show the reverse effect, a lesser fixation capacity, when the concentration of K was increased by one more addition of K_2SO_4. In each case the surface addition of K_2SO_4 had to pass through the full depth of either Ca-or Mg-fortified soil before appearing in the leachings. When any chemical explanation is advanced to account for the behavior of the heavy MgO treatments, the question immediately arises as to why the CaO treatments failed to function in the same manner. The unabsorbed residues of MgO were more soluble than the unabsorbed residues of CaO and the Mg complexes hydrolyze more readily than the Ca complexes.

The heavy additions of the two materials, CaO and MgO, exert a distinctly divergent physical effect upon the soil. The former gives a granulation effect and a quick outgo of rain water, whereas the latter gives a sticky dispersed soil system and a protracted period of leaching. The effect that these physical variants may have upon the prevailing concentrations of solutes, including K, may hold an explanation of the anomaly noted. The explanation would be of academic interest, but no practical problem is involved. No such excessive treatment of MgO would be expected and the resultant toxicity upon plant growth could be foretold. A soil system of excessive alkalinity would be induced and a definite paucity of calcium would ensue as a result of the repression of the hydrolysis of calcic compounds and the "salting out" of calcium carbonate.

The fact remains, however, that the residues of all economic additions of MgO exercise the same repressive effect that is exercised by both light and excessive additions of CaO upon the solubility of soil potassium, as measured by rainwaters under conditions that admit of alternate wet and dry conditions. This holds for both low concentrations and those built up by additions of soluble potassium.

SUMMARY AND CONCLUSIONS

At the conclusion of a 12-year study of the effect of 21 full-depth incorporations of calcic and magnesic materials and 3 forms of sulfur upon outgo of Ca, Mg, K, and SO_4, the residual systems were given annual surface additions of potassium sulfate, at the rate of 200 pounds of K_2O per 2,000,000 pounds of soil during the succeding 6 years to determine the effect of the calcic and magnesic residues upon

the outgo and fixation of the added K. The K results are given in terms of pounds leached and p. p. m. concentration in the leachings, together with parallel Ca + Mg values for the 12-year and succeeding 6-year periods.

In each case some increase in outgo of K was obtained from the first addition of K_2SO_4; but in general, substantial increases in outgo were not registered until after the third addition.

The increases in outgo of K from the previously untreated soil and from the more acid sulfur-treatment controls were observed earlier and in greater totals than in the case of all economic additions of CaO, MgO, limestone, and dolomite.

Every addition of calcium at all rates effected a repression in outgo of K, the repressive effect becoming greater with increase in rates of liming. The light additions of MgO alone and with sulfur supplements exerted the effect comparable to that exerted by CaO. Initially, the 32-ton MgO additions exerted the same repressive effect that they had registered upon the native supplies of K during the preceding 12-year period; but, beginning with the third year, the 32-ton treatments greatly accelerated and enhanced the totals for K outgo.

The concentrations of Ca + Mg in the leachings from the light additions of burnt lime, limestone, dolomite, and MgO during the first 12-year and the subsequent 6-year period were comparable, as explained by K-Ca + Mg exchange and greater increment from rainwater during the latter period. The units that received the initial incorporations of $FeSO_4$, pyrite, and S showed a decided decrease in the concentration of Ca + Mg in the leachings of the 6-year period. But the concentrations found for the 32-ton additions of MgO were still materially greater than those found for the 32-ton additions of CaO. The reversal in the effect induced by the large residues of MgO after 14 years cannot be explained, therefore, by variant concentrations of Ca and Mg.

It is pointed out that this anomaly obtains only with excessive additions of magnesium oxide and that even after a period of 18 years the residues from all economic additions of Ca and Mg exert a repressive effect upon the outgo of K from a built-up supply of that element.

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ANALYSIS OF *CROTALARIA JUNCEA* WITH SPECIAL REFERENCE TO ITS USE IN GREEN MANURING AND FIBRE PRODUCTION[1]

B. N. SINGH AND S. N. SINGH[2]

GREEN manuring and the cultivation for this purpose of quickly growing crops, chiefly of the leguminous order, has been a very ancient farm practice in most parts of the world associated with agriculture. Of the large number of crops used for this purpose, probably none answers the purpose better than *Crotalaria juncea*—a fairly rapid-growing plant, with a relatively short life cycle, capable of being raised without any special soil preparation. When ploughed down it requires a comparatively short time to decay, and besides acting as an important fertilizer it also yields fibre. The use of crotalaria as a green manuring and fibre crop has led the experimental agriculturists to advocate its cultivation in areas deficient in manurial constituents and in such other localities where other money crops may not be successfully grown for want of soil fertility. The scientific importance of this crop as a green manure in increasing soil fertility and its rôle in inducing physico-chemical changes in the soil which directly or indirectly bear upon plant growth have, however, been recognized only lately.

A critical survey of the literature indicates that the aspects along which work has been conducted during the last two decades centre round the determination of the best method of burying, the effect of addition of extra manure, and the influence of rainfall and water supply on the subsequent changes induced in the soil. Its utility in improving the physical configuration and the water-holding capacity of the soil, its usefulness as a reserve for the retention and circulation of plant food which would otherwise be washed away, as well as its rôle in acting as a substrate for the nitrogen-fixing bacteria are additional aspects along which useful work has been conducted. Little or no attention, however, has been given to the nature and the amount of materials formed at successive stages of growth of crotalaria and which constitute the substratum for all changes subsequent to the incorporation of the plant in the soil. Not infrequently the observed harmful after effects of green manuring are to be traced to the lack of this fundamental knowledge.

In order to determine, therefore, the period when the plant can yield the maximum amount of organic matter, contribute the most to the fertility of the soil in terms of nitrogen content, return to the soil the maximum amount of manurial nutrients, and provide the best quality of fibre, analyses of the plant as a whole and of its various parts were made at successive stages throughout the life cycle with reference to the more important inorganic and organic constituents. The data thus obtained are compared with parallel observations on

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growth, conducted under field conditions, and suggestions made with regard to the stage in the life cycle of this plant when its use would result in the maximum possibilities of both soil fertility and fibre production.

METHODS AND MATERIALS

A pure strain of *Crotalaria juncea* was sown broadcast early in July with the onset of the rains on the experimental farms of the Institute. When the seeds germinated, seedlings of the same age and equal vigor were labelled and retained. For the determination of the dry matter, a large number of plants at successive stages of their development were carefully dug out of the soil with their root system intact, washed carefully in a stream of water, separated into their component parts, and dried to constant weight in a steam oven regulated at 100°C.

For the estimation of various organic constituents, a portion of the material was prepared after the method of Lind and Tottingham (5)[3]. Aliquot samples of the dried material so obtained were analysed with respect to different carbohydrates, celluloses, and fats. For the estimation of the essential elements, including calcium, potassium, magnesium, sulfur, and phosphorus, the official and tentative methods of analysis (1) have been used and need not be repeated here.

On the basis of the morphological characteristics, the entire life period of the plant has been segregated into four distinct stages for the purpose of these studies. The first or "juvenile" (young) stage is associated with scant vigor as demonstrated by dry matter production (Fig. 24), thin hairy stem, immature and few root nodules, and few small leaves from 20 to 25 mm in length, slightly reddish and hairy on the under surfaces. This stage lasts for 30 days after germination The second or "adolescent" stage is characterized by rapid growth, a ramification of root hairs in all directions, thick yet flexible stem, branching of the stem with secondary and even tertiary arms, dense foliage, the whole forming a canopy, leaves bigger, 3 to 6 inches long and 1 to 3 cm broad, brighter in appearance and greenish in color, indicating better development of chlorophyll than in the first stage. During the present investigation this stage continued up to the 75th day where the initiation of the reproductive phase commenced, culminating in a third phase which is antecedent to the full-ripe stage, and which is designated as the "partial senescence" stage. It is associated with the flowering and setting of fruits, hard woody stems with mature fibre, yellowish leaves, shedding of the older leaves probably on account of the want of the nutritional availability. This stage lasted for 20 to 25 days after the adolescent stage, and merged into the full-ripe or "senescent" stage where more or less all the functional activities, a detailed discussion of which is beyond the scope of the present study, begin to sink and finally stop, resulting in the drying up of the plant. As this stage appeared at about the 105th day the experiments were discontinued. The results of the present findings are discussed both on the basis of the various physiological stages as well as age in days after germination.

The investigations were planned to determine the stage at which *Crotalaria juncea* abounds in maximum organic and inorganic constituents, the period at which the plant attains its maximum fibre content, the stage of development at which the best fibre quality is to be had, and a judicious selection of the period when the plant would have maximum possibilities for either manuring or fibre production, or both. A consideration of the rôle of manurial constituents in

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[3]Figures in parenthesis refer to "Literature Cited", p.227.

organic synthesis and growth metabolism in general and other detailed studies on crotalaria will be taken up in a future communication.

RESULTS

FERTILIZING CONSTITUENTS

The percentage of most of the organic constituents synthesized by the plant at successive stages of its growth is found to increase continuously during the early part of the life cycle of the plant (60 days).[4] (See Fig. 4.) The reducing sugars, however, decline from the young to the senescent stage probably on account of their being continuously drawn upon to supply energy for the manifold plant activities as well as their conversion into other complex organic materials which ultimately make up the entire plant body. Fats, on the other hand, exhibit a decline only in the juvenile and the first half of the adolescent stage (45 days) when their use in nurturing the young seedlings brings down their percentage. When the seedlings resume their normal photosynthetic activity and a fresh supply of organic materials is available, the excess carbohydrates seem to be converted into fats, the content of which thus increases during the subsequent periods of the life cycle.

If crotalaria is to be used for green manuring, the plowing under of the plants at a stage when either of these organic constituents, *viz.*, reducing sugars or fats, are continuously decreasing would thus result in a decreased supply of organic matter in the soil, the lack of which may directly or indirectly fail to improve the anticipated physical characteristics of the soil as well as its water-holding capacity. With decreased availability of organic materials, as shown by Cates (2), humus formation may also be affected, which may, in turn, influence the physico-chemical reaction in the soil and induce such other changes in the liquid phase of the soil nutrients which may affect plant growth and thereby culminate in decreasing the fertility of the field.

A closer examination of the data reveals that certain organic substances, such as total carbohydrates and sucrose, attain a maximum when the plant is in its full adolescent stage (60 to 75 days). (See Fig. 4.) Fats and celluloses, however, constituting no less important a fraction of the organic matter, attain their highest values only towards the close of the life cycle. Were the burying of the crop, therefore, delayed till this stage, negative results would follow for at this stage the low values of both sucrose and total carbohydrates would greatly reduce the manurial value of the crop. Moreover, the presence of celluloses in larger quantities after the adolescent stage (Fig. 4) reduces the manurial value of the crop since the decomposition of the mature woody fibre and its thorough incorporation into the soil is not so easily secured, resulting in great damage to the succeeding crop through an attack of white-ants.

In all questions regarding soil fertility stress is laid on the available nitrogen in the soil. The loss incurred due to absorption by growing plants as well as to leaching frequently reduces the fertility level to such an extent that succeeding crops do not maintain good growth.

[4]Age of the plant in days after germination.

On all such soils, the use of crotalaria as a green manure is advocated as a source of nitrogen.

Determination of the nitrogen content reveals that with the growth of the plant the nitrogen increased gradually up to the latter part of the adolescent stage (60 days). (See Fig. 4.) The subsequent decline in the nitrogen content after this period, as well as the relatively low nitrogen content of the plant prior to this stage, clearly indicates that plowing under the crop before or after this critical period would reduce the maximum manurial efficiency of the crop in respect to nitrogen.

Besides nitrogen other inorganic constituents are also useful in one way or another in initiating good growth in plants. It is interesting to note that the percentage of ash in the dry matter gradually increases in the same direction as the percentage of nitrogen to reach a maximum when the plant is in its full adolescent stage (60 days). (See Fig. 4.) A decline in the ash content is to be noted after this stage, revealing thereby that the maximum amount of mineral elements present in the crop may be plowed under with advantage within two months after germination. The curves representing the percentages of the various elements show certain fluctuations with regard to their optimum amounts (Fig. 8), but calcium and potassium, which contribute much more than any other elements to the composition of the plant body, attain their maximums, like most of the organic constituents, when the initiation of the reproductive phase commences (60 to 75 days), and hence the plowing under of the crop during this period should provide the maximum amount of these important constituents to the soil.

As to the absolute quantities of these materials for different parts of the plant as well as for the plant as a whole, reference to Figs. 9 to 23 indicates that the majority exhibit a slow increase at first, followed by a steep rise which, in turn, rounds off to almost a level value to be succeeded very soon by a characteristic decline. The curves in every case resemble the time-weight curves for growth (Fig. 24). The maximum output of organic and inorganic constituents per plant is attained when the plant is in its partial senescent stage (90 days). (See Figs. 21 to 23.) Corresponding results are seen on reviewing the data calculated on an acreage basis for the entire plant (Table 1). If the addition of the highest amount of fertilizing constituents to the soil is the final goal of green manuring without taking into account the nature of the material, its rate of decomposition, and the fraction available to the succeeding crop, the entire plant may be plowed under in its partial senescence stage when it will add to the soil the highest quantity of nutrients obtainable in the entire life period of the crop. But quantity of nutrients is not the only criterion of successful green manuring because the hard woody stem at this stage, instead of leading to an improvement of the soil, will actually cause great damage, as previously mentioned.

On the other hand, the absolute quantities of the majority of the fertilizing constituents which contribute the most to the manurial efficiency of the plant both per acre and per plant (Table 1, and Figs. 9 to 20) for the leaves and roots attain their highest values only

TABLE 1.—*Fertilizing constituents in pounds per acre added to the soil by incorporating crotalaria at successive stages of its life cycle*

Age in days	Sample	Reducing sugars	Fats	Total carbohydrates	Sucrose	Celluloses	Nitrogen	Ash	Calcium	Potassium	Phosphorus	Magnesium	Sulfur
	Juvenile (Young) Stage												
1 . . .	Tops and roots	0.6	1.08	1.6	0.26	0.36	0.54	0.62	0.16	0.05	0.03	0.03	0.12
	Entire plant	0.86	1.32	2.1	0.33	0.99	0.72	0.79	0.19	0 06	0.03	0.04	0.19
15. . .	Tops and roots	1.47	2.67	5.44	0.92	2.11	1.58	1.98	0.46	0.28	0.11	0.08	0.62
	Entire plant	2.01	3.10	6.63	1.15	3.16	1.94	2.27	0.56	0.29	0.12	0.09	1.02
30	Tops and roots	18.0	30.3	69.9	12.04	13.3	22.4	32.7	9.30	3.97	1 44	0.86	10 39
	Entire plant	25.2	35.1	89.5	17.20	50.9	27.6	37.8	10.7	4.31	1 65	1.23	11.25
	Adolescent Stage												
45. . . .	Tops and roots	51.8	46.1	227.1	47.8	59.7	81.2	108.5	42 6	22 80	2.79	3.39	28.11
	Entire plant	64.1	106.0	338.1	62.4	191.1	105.2	122.2	43.8	23.29	4.05	4.21	37.55
60. . .	Tops and roots	175.7	467 4	1,204.5	226.3	282.2	396.2	601.3	219.2	131.30	13.33	20.33	137.54
	Entire plant	267.9	676.3	2,064.2	480.6	1,376.9	683.8	962.5	332.9	202 52	21.32	21.25	168.11
75. . .	Tops and roots	216.3	745 1	1,687.1	417.7	489.2	473.9	840.6	276.1	188.30	15.71	35.88	178.04
	Entire plant	313.5	1,055.2	2,837.1	720.8	2,153 1	781.1	1,204.9	431.4	309.94	28.51	51.95	190.71
	Partial Senescent Stage												
90. . . .	Tops and roots	231 6	954 2	1,649.6	362 3	433.3	447.3	573.8	232 7	197.67	15.94	40.46	130.00
	Entire plant	369.3	1,607.8	3,342.9	739 9	2,863.3	783.9	1,351 1	502.1	424.85	34.06	71.41	337.60
	Senescent Stage												
105.	Tops and roots	41.4	629.7	906.9	145.9	300.9	158.4	261.5	31.3	105.86	8.48	10 46	46.68
	Entire plant	151.9	2,220.9	3,055.8	509.5	3,350.5	473.8	1,264.2	170.6	455.43	31.91	43.59	169.52

at the time of the initiation of the first bud (75 days), whereas their percentage in dry matter, both in the entire plant and also in the various parts of the plant, is highest during the last fortnight of the adolescent stage (60 days). On the basis of the calculations and with the due consideration for the woody nature of the stem after the adolescent phase, it appears, therefore, that the green manuring either with the entire plant or with tops and roots alone at a stage coinciding with the initiation of the reproductive primordia (75 days) should result in maximum manurial value of the crop.

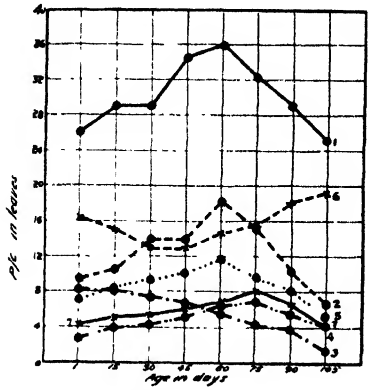

FIG. 1.—Percentage of various plant constituents in leaves (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

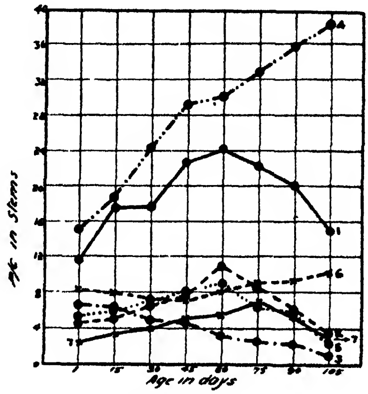

FIG. 2.—Percentage of various plant constituents in stems. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

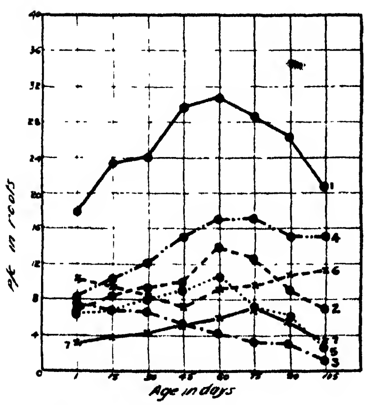

FIG. 3.—Percentage of various plant constituents in roots. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

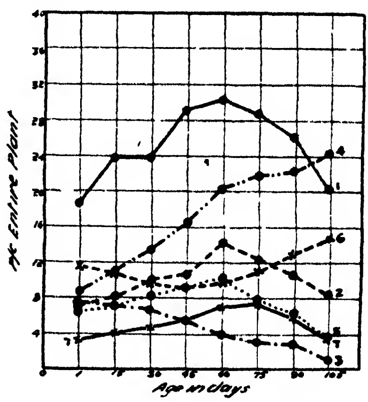

FIG. 4.—Percentage of various plant constituents in entire plants. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

MANURIAL EFFICIENCY OF PLANT PARTS

To test the possibilities of green manuring with different parts of the plant, the root, stem, and leaf were analysed as to their more important organic and inorganic constituents at successive stages of growth. The leaf appears to be richest in the above materials (Figs. 1, 5, 9 to 20), while next in order are the root (Figs. 3, 7) and stem (Figs. 2, 6). The utility of the stem as a fibre-producing organ and of the leaf and the root, which are richer in the manurial constituents, for green manuring, was further tested by field experimentation. The effect of successful green manuring with tops and roots is extra-

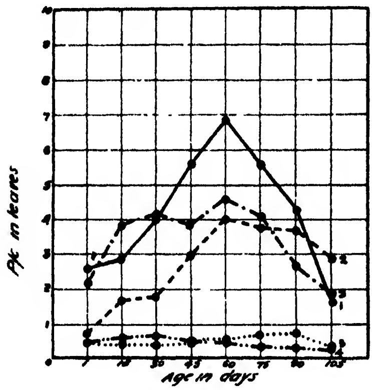

FIG. 5.—Percentage of inorganic constituents in leaves. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

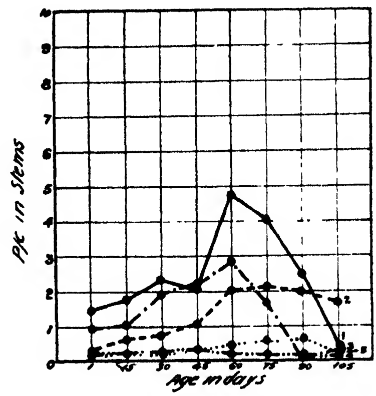

FIG. 6.—Percentage of inorganic constituents in stems. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

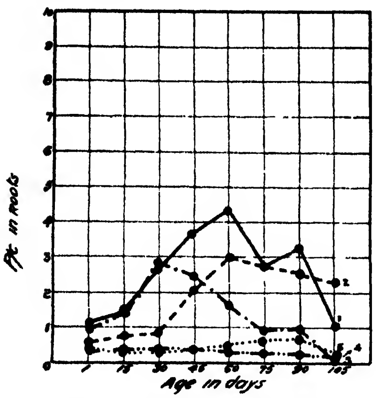

FIG. 7.—Percentage of inorganic constituents in roots. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

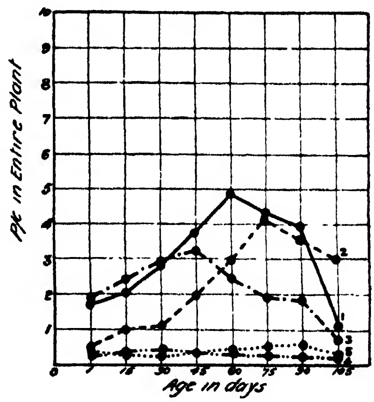

FIG. 8.—Percentage of inorganic constituents in entire plants. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

ordinary. The texture and the color of the soil are altered and the effect on the succeeding crop in luxuriance and rapidity of growth is remarkable, a discussion of which will be taken up in a later paper.

In the light of the present investigations it may be remarked that the leaf, containing simpler carbohydrates and proteins, is easily decomposed in the soil and adds to the fertility of the soil at a much earlier stage than the stem. The celluloses contained in the stem are highly complex materials, difficultly attacked by micro-organisms and, in consequence, decomposition of the stem requires a long time. These undecomposed stems result in too open a texture of the soil, causing considerable damage to the succeeding crop. It may thus be expected that green manuring with tender parts, such as the top

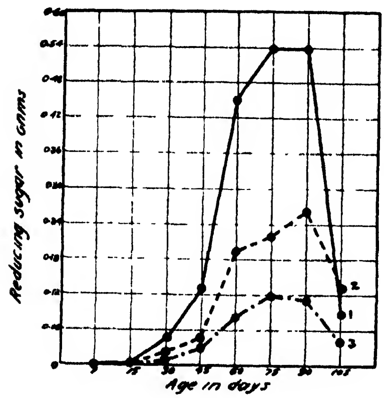

FIG. 9.—Reducing sugars in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

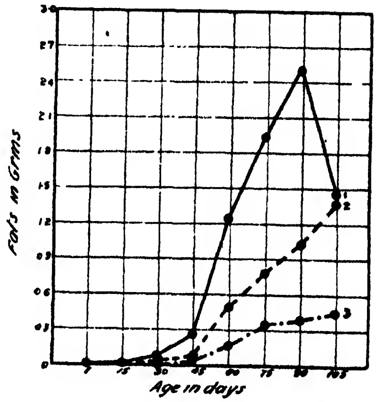

FIG. 10.—Fats in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

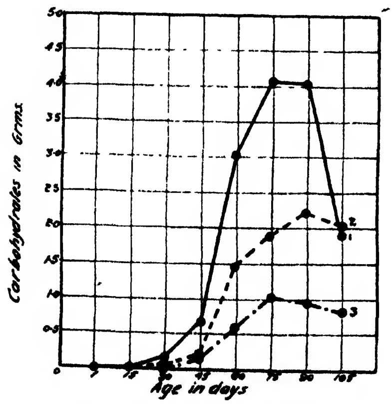

FIG. 11.—Carbohydrates in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

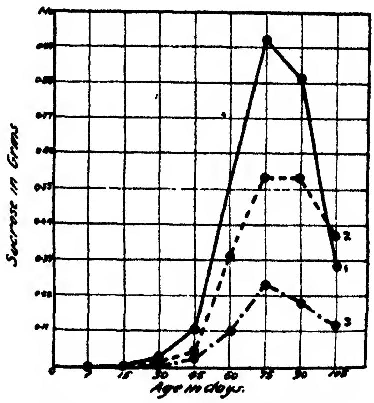

FIG. 12.—Sucrose in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

and the leaf, would result in a rapid availability of nitrogen compounds for the growth of the developing plant. On the other hand, manuring with stems, with their less rapid decomposition, adds much less organic and inorganic constituents than may be obtained from the leaves. The conclusion is thus obvious that greater manurial efficiency may be attributed to the leaf and that the stem, being less useful in this direction, may well be utilized for other purposes. The root, on the other hand, stands midway between the leaf and the stem in organic and inorganic constituents. The roots rot earlier than the stems and if incorporated with the soil along with the leaves may maintain a supply of readily available nitrogenous compounds. The decomposition of the roots at a slower rate may also help the plant

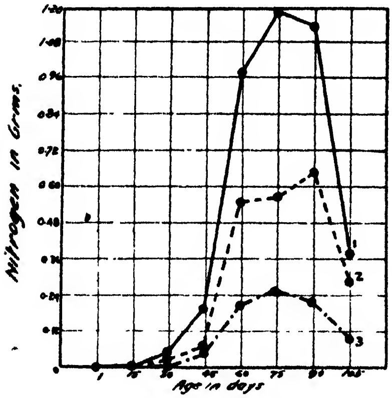

FIG. 13.—Nitrogen in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

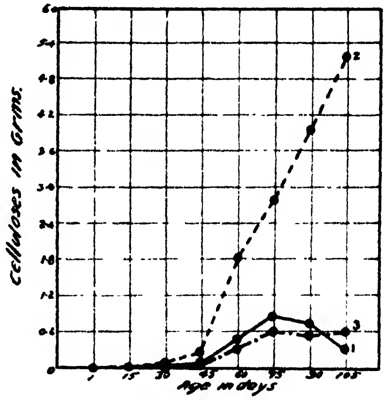

FIG. 14.—Celluloses in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

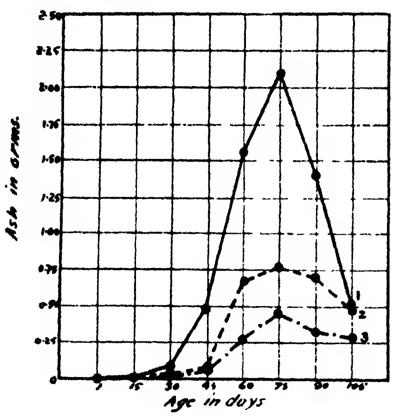

FIG. 15.—Ash in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

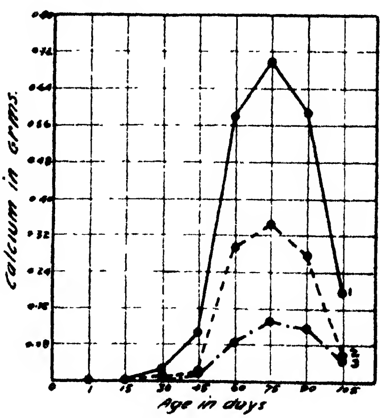

FIG. 16.—Calcium in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

in overcoming the nitrogen deficiency which may be felt at later stages of growth when the soil is relatively poor in nitrogen.

FIBRE CONTENT

To obtain an idea of the fibre content of the plant at successive stages of its growth, the plant was analysed with respect to celluloses. The quantity of fibre as judged by the amount of celluloses in the dry material was found to increase from the young to the senescent stage when the plant was 105 days old (Fig. 4). The stem showed the highest amount of celluloses (Fig. 2) and the leaf the least (Fig. 1). Field experiments reveal that the tonnage of the fibre is also highest at this stage. The length, tensile strength, and spinning value

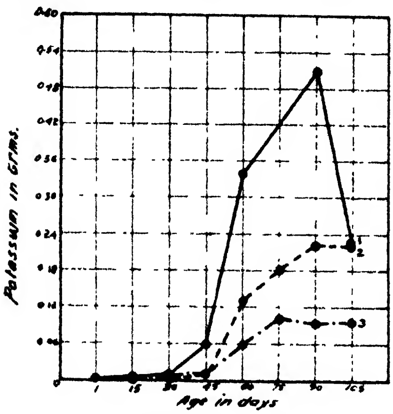

FIG. 17.—Potassium in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

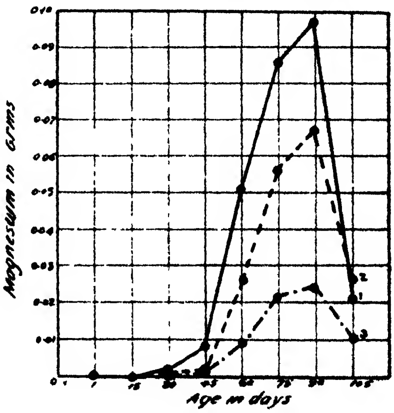

FIG. 18.—Magnesium in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

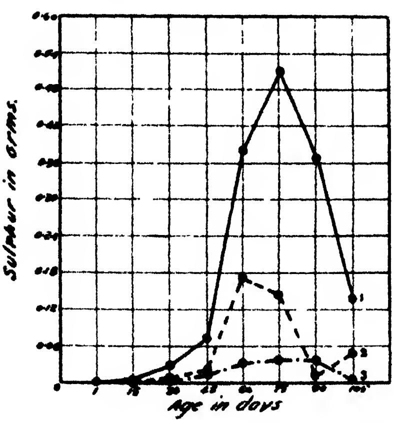

FIG. 19.—Sulfur in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

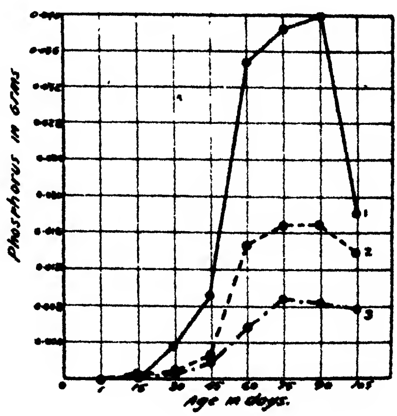

FIG. 20.—Phosphorus in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

do not seem to follow the tonnage, however, as it is observed that the best results with regard to these qualities are only obtainable when the plant is in the adolescent stage (75 days), and that thereafter the development of wood considerably reduces the quality of the fibre. These observations are further supported by the investigations of Howard (3) and Joshi (4).

It seems desirable to mention that the cutting of the stems during the pre-flowering stage will result in better fibre quality and consequently will fetch a higher market value. On the contrary, if the aim of the cultivator is to obtain the maximum possibilities of both green

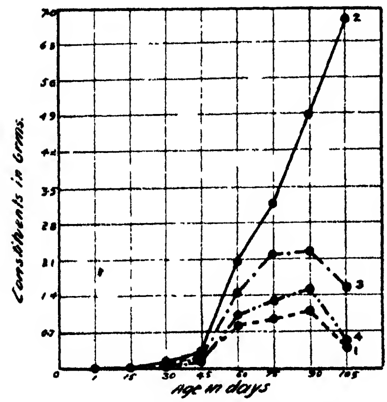

FIG. 21.—Constituents in grams in the entire plant. (1) Reducing sugars, (2) fats, (3) sucrose, and (4) calcium.

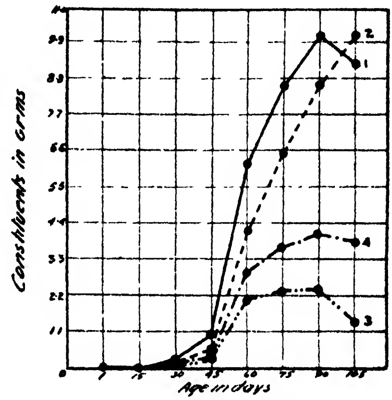

FIG. 22.—Constituents in grams in entire plant. (1) Total carbohydrates, (2) celluloses, (3) nitrogen, and (4) ash.

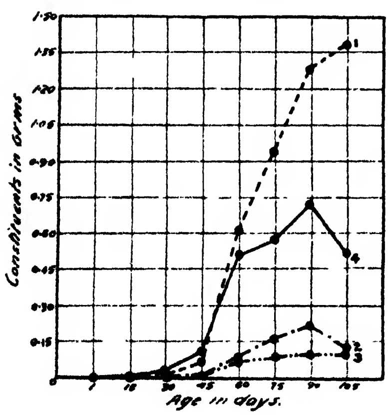

FIG. 23.—Constituents in grams in the entire plant. (1) Potassium, (2) magnesium, (3) phosphorus, and (4) sulfur.

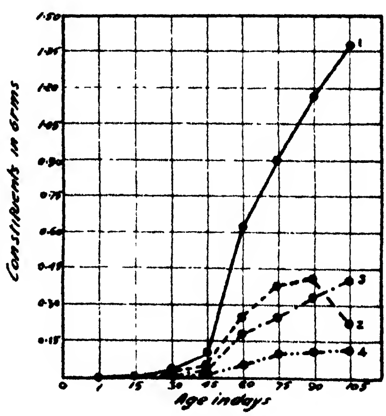

FIG. 24.—Production of dry matter in grams in the entire plant as well as different plant organs. (1) Entire plant (2) leaves, (3) stems, and (4) roots.

manuring and fibre production, it is suggested that the leaves and roots be plowed under for green manuring and the stems used for fibre production when the plant is in its full adolescent stage (75 days) when it is expected to add to the soil the highest amounts of organic and inorganic plant constituents, as previously discussed.

SUMMARY AND CONCLUSIONS

Crotalaria juncea was analysed as to its organic and inorganic constituents at successive stages of its life cycle. Simultaneous growth studies were also conducted and the data on the chemical composition of the plant calculated in terms of percentage of dry matter, of absolute weight of the plant, and the amount per acre to be added to the soil.

The percentages of organic matter, nitrogen, and other essential elements in general increased with the age of the plant and attained a maximum during the later part of the adolescent stage (60 to 75 days) both in the entire plant as well as various parts.

The absolute quantities of these materials for the entire plant, as well as the amounts calculated on an acre basis, attained maximum values when the plant was in its partial senescence (90 days), while for the different parts, especially the leaves and roots, the maximum was attained only at the initiation of the reproductive phase (75 days).

The analysis of the various parts clearly indicates that the leaves have the highest manurial efficiency, with the roots and stems in the order indicated.

Thus, on the basis of the development of the plant and its composition, it is inferred that the best period for green manuring would be when the adolescent stage is about at an end and when the reproductive phase commences.

The fibre content, as judged by the percentage of celluloses, reaches a maximum when the plant is in its senescent stage, but the best quality of fibre can only be had when the plant is in its adolescent stage.

If both green manuring and fibre production are desired, the leaves, tops, and roots could be plowed under with advantage while the stem could be used for fibre when the plant is 75 days old without in any way markedly affecting the fertility of the land.

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NITROGEN AND ORGANIC CARBON OF SOILS AS AFFECTED BY CROPS AND CROPPING SYSTEMS[1]

W. H. METZGER[2]

THE relative efficiencies of various crops and cropping systems in conserving soil nitrogen has been a matter of considerable interest to agronomists for many years. Many notable attempts have been made to measure such relative efficiencies. Only one of these attempts can be mentioned here. Salter and Green[3] have determined the effect of the following crops and cropping systems on the soil's supply of nitrogen and organic carbon: Corn, wheat, and oats each in continuous culture, a 5-year rotation containing a clover and timothy hay crop, and a 3-year rotation containing a clover hay crop. Furthermore, they have presented a means by which the efficiency of a rotation or an individual crop either in rotation or in continuous culture may be expressed mathematically Assuming (a) that a given portion of the nitrogen and carbon of the soil, characteristic of the type of culture employed, is utilized in the production of each crop, and (b) that the gain in these constituents accounted for by the crop residues is roughly proportional to the size of the crop produced, the following equation was proposed by these workers. $N_t = N_oK^t$, in which N_t is the nitrogen content of the soil after "t" years, N_o is the nitrogen content at the beginning, and K represents the fraction of the nitrogen remaining after growing the crop a single year. Using the "K" values obtained from experimental data for the nitrogen and carbon of soils continuously cropped with various crops, the corresponding value for a crop used in rotation but not in continuous cropping can be calculated.

Determinations of nitrogen in the soil of many of the plats of the soil fertility project at the Kansas Agricultural Experiment Station were made in 1915, 1923, and again during the period of 1932 to 1934, and therefore an opportunity was afforded to test the assumptions involved in the formulation of the equation. The rates of change in the nitrogen content of the soil had probably become fairly well stabilized when the 1915 samples were taken, since six cropping seasons had elapsed after the establishment of the project before these samples were collected. For a series of 12 plats in a 3-year rotation of corn, cowpeas (or soybeans), and wheat, a comparison of the experimentally determined values with the values calculated

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[2]Associate Professor of Soils. The writer is indebted to Professor R. I. Throckmorton, Head of the Department of Agronomy, under whose direction the soil samples were taken in 1915 and 1923, and to Dr. C. O. Swanson, Head of the Department of Milling Industry, in whose laboratory the 1915 samples were analyzed.

[3]SALTER, R. M., and GREEN, T. C. Factors affecting the accumulation and loss of nitrogen and organic carbon in cropped soils. Jour. Amer. Soc. Agron., 25:622–630. 1933.

for 1923 and 1934, using the actual values for 1915 as a basis, is shown in Table 1.

TABLE 1.—*Comparison of the calculated and the experimentally determined nitrogen content of the soil of a series of plats devoted to a 3-year rotation.*

Plat No	Nitrogen, 1923, pounds per acre		Nitrogen, 1934, pounds per acre	
	Calculated	Actual	Calculated	Actual
1	3,131	3,040	2,649	2,840
2	3,088	2,840	2,310	2,820
3	3,076	3,060	2,805	2,840
4	2,916	2,880	2,602	2,680
5	2,863	2,520	1,965	2,660
6	2,835	2,880	2,698	2,600
7	2,878	2,840	2,634	2,720
8	2,837	2,760	2,417	2,580
9	2,837	2,840	2,708	2,700
10	2,754	2,740	2,608	2,640
11	2,834	2,780	2,623	2,760
12	2,809	2,680	2,451	2,740

The soil samples taken in 1923 were sealed in Mason jars and were not analyzed until 1934. Unfortunately, a few of them were sealed before they became air-dry. Reducing conditions were produced and some loss of nitrogen may have occurred. The samples from plats 2, 5, and 12 were sealed moist and the "actual" nitrogen values for these plats for 1923 appear low. As a result, the calculated values for 1934 are, relatively, still lower. On the whole, however, the results show reasonably good agreement between the "actual" values and the calculated values. The "actual" values for 1934 are in most cases slightly higher than the calculated values, perhaps indicating that the rate of loss of total nitrogen has been checked and an equilibrium condition, characteristic of the cropping system and the climate, is being approached.

Nitrogen and organic carbon data were obtained in 1915 and again in the period of 1932 to 1934 for plats devoted to the following cropping systems: Continuous wheat, continuous alfalfa, a 3-year rotation of corn, cowpeas or soybeans, and wheat, and a 16-year rotation in which alfalfa occupies the land for 4 years, and a 3-year rotation of corn, wheat, and wheat[4] takes up the remaining 12 years. In each of these cropping systems the entire crop production is removed from the land. Soybeans were substituted for cowpeas in the 3-year rotation in 1929, hence in the period represented in this study four cowpea crops and two soybean crops were grown in this rotation. The soybean crop is drilled in rows, 7 inches apart, and removed as hay and the cowpea crops were handled likewise. The nitrogen and organic carbon data are shown in Table 2.

"K" values were obtained for wheat and alfalfa in continuous culture and by applying these to the 16-year rotation data the corresponding value for corn was determined. The equation then

[4]Originally corn, corn, and wheat, but changed in 1921.

TABLE 2.—*Nitrogen and organic carbon in the soil* of unfertilized plats under various cropping systems, average of 4 plats for each cropping system.*

Crop or cropping system	Nitrogen in pounds per acre for the year indicated		Organic carbon in pounds per acre for the year indicated	
	1915	1934	1915	1934
16-year rotation.....	3,610	3,150†	40,700	32,880†
3-year rotation.......	3,065	2,705	38,700	27,890†
Continuous wheat	2,685	2,404†	38,350	29,750
Continuous alfalfa. .	2,550	2,910	32,050	31,560

*Surface soil (0-6 2/3 inches)
†1932

became $N_{1932} = N_{1915}\ K^5_{corn}\ K^8_{wheat}\ K^4_{alfalfa}$.[5] Since K_{corn} was the only unknown, its value could be calculated. This calculated value for corn applied to the data from the 3-year rotation, along with the "K" value for wheat in continuous culture, gave the "K" value for cowpeas (or soybeans). The difference between the "K" value for a given crop or cropping system, expressed as percentage, and 100 represents the loss or gain of the nitrogen or carbon, as the case may be, expressed on a yearly basis. The values so obtained for the various crops and cropping systems are shown in Table 3.

TABLE 3.—*Percentage annual gains and losses of nitrogen and organic carbon of the soil as affected by crops and cropping systems.*

Crop or cropping system	Percentage annual gain or loss	
	Nitrogen	Organic carbon
16-year rotation....	—0.82	—1.24
3-year rotation.....	—0.66	—1.69
Wheat, continuous.	—0.64	—1.18
Alfalfa, continuous..	+0.71	—0.10
Corn (calculated)..	—2.28	—2.27
Cowpeas (calculated)	+0.94	—1.72

The analyses for 1915 were made during that year and were not made by the same analyst who worked with the 1934 samples. The method used for nitrogen determinations, however, was substantially the same and it is believed the results are strictly comparable. In the case of the carbon data the methods differed. The 1915 results were obtained by the dry combustion method, while the wet oxidation method as outlined in Methods of Analysis (A. O. A. C., Ed. 2) was used in 1934, owing to a lack of equipment needed in the dry determination.

The results, including the calculated data, indicate that corn in continuous culture is nearly 3 times as destructive of the soil's

[5]In the 17 cropping seasons here represented, alfalfa occupied the land during the years 1926, 1927, 1928, and 1929.

nitrogen as the 16-year rotation and 3.5 times as destructive as the 3-year rotation or continuous wheat. It is probable that several factors enter into the causes for the more rapid disappearance of nitrogen under corn than under wheat, but in the case of these experiments, at least, the greater extent of erosion on corn land as compared to wheat land is undoubtedly of major importance.

The results for carbon, while possibly showing greater losses than would have appeared had both groups of determinations been made by the same method, are at least comparable among themselves. The trend of the carbon changes is similar to that of the nitrogen changes. Again continuous corn is indicated by the calculated data to be the most destructive cropping system studied and the presence of this crop in the rotations renders them fully as destructive or slightly more so than continuous wheat.

It is interesting to note that while alfalfa has caused gains in the nitrogen supply of the soil and about maintained the carbon content, cowpeas (or soybeans) are indicated to have increased the nitrogen slightly more per year than alfalfa but to have effected a distinctly greater loss of carbon. Since the values for cowpeas (or soybeans) could be arrived at only by employing the calculated values for corn, they may be subject to serious error. There have been very few data presented, however, which offer satisfactory evidence that soybeans or cowpeas, provided serious erosion is prevented, may not as effectively conserve or increase nitrogen of the soil as alfalfa over the period of time the crop actually occupies the land. These data suggest that the question may at least be worthy of further study. The indicated loss of carbon under cowpeas is possibly too great for reasons given previously, but it is perhaps significant that, although all crops and cropping systems have either about maintained or slightly reduced the carbon: nitrogen ratio since 1915, the greatest reduction occurred in the case of the 3-year rotation.

Data presented by White[6] and by Salter and Green[7] show a close relationship between the organic matter content of the soil and the total crop production over a period of years. The data for unfertilized plats of the soil fertility project of the Kansas Experiment Station show a very close relationship between total nitrogen and crop production over a period of 25 years. A similar relationship is shown between organic carbon and crop production. The data for total nitrogen and crop production are shown in graphic form in Fig. 1. The correlation is extremely high, $r = .978 \pm .008$. The regression line extended shows a value for the residual nitrogen with zero crop production of about 1,300 pounds, a value similar to that obtained by Salter and Green[8] for plats at the Ohio Experiment Station. The Kansas data also substantiate the Ohio data in the indication that each unit of crops produced contributes about the same to the soil's supply of nitrogen and organic matter regardless of the yield. In the data here presented it appears this was true with respect to the three

[6]WHITE, J. W. Crop yields in relation to residual soil organic matter. Jour. Amer. Soc. Agron., 23:429-433. 1931.
[7]*Loc. cit.*
[8]*Loc. cit.*

cropping systems, i.e., 16-year rotation, 3-year rotation, and continuous wheat, in spite of the fact that one of these systems included alfalfa, one had soybeans, and the third had no legume. This fact may be interpreted as an indication that the nitrogen in the soil of the unfertilized plats of these cropping systems has become fairly

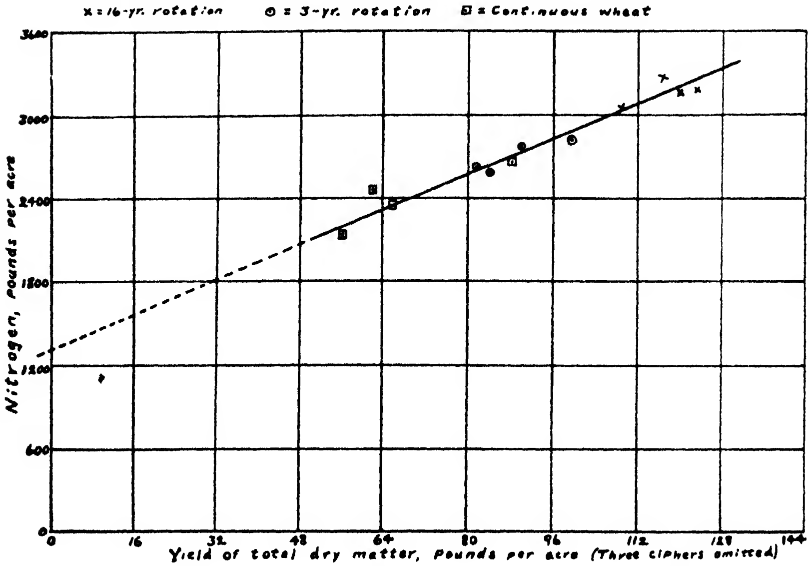

FIG. 1.—Relation of total crop production to the total nitrogen of the soil of unfertilized plats.

stabilized at a point characteristic of the cropping system in each case. It was pointed out on a preceding page that the retarded rate of decline of the soil's nitrogen during the period of 1923 to 1934 as compared to the rate for 1915 to 1923 also indicated such a stabilization.

Equilibrium conditions with respect to the soil's nitrogen supply are apparently approached rather rapidly under the soil and climatic conditions represented by these experiments. This is indicated by the fact that manure applications amounting to 40 tons in each of the two rotations and 60 tons in the case of continuous wheat have apparently failed to increase the nitrogen supply of the soil. In the continuous alfalfa experiment, 120 tons of manure during the same period of time have produced some increase in soil nitrogen but scarcely more than could be accounted for by the increased crop residues.

SUMMARY

Studies have been conducted at the Kansas Experiment Station to determine the effect on the soil nitrogen and organic carbon of the following crops and cropping systems: Wheat continuous, alfalfa continuous, a 3-year rotation of corn, cowpeas (or soybeans), and wheat, and a 16-year rotation in which alfalfa is grown for 4 years

and a 3-year rotation of corn, wheat, and wheat takes up the remaining 12 years. Corn was indicated to be much more destructive of nitrogen and carbon than any other crop or cropping system. Both alfalfa and cowpeas appear to have added to the soils nitrogen supply, but the latter was more destructive of carbon than the former. Continuous wheat produced about the same effect as each of the two rotations.

Total crop production over a period of 25 years and total nitrogen of the soil were shown to be highly and positively correlated. Manure applications failed to produce significant increases of nitrogen or carbon which could be attributed directly to the manure and not to increased crop residues. The nitrogen of the soil of the experimental plats studied appears to be definitely approaching an equilibrium characteristic of the crop or cropping system employed.

ARE UNIFORMITY TRIALS USEFUL?[1]

H. H. LOVE[2]

FROM time to time the suggestion has been made that for a field which is to be used for cultural experiments or studies in crop rotation and soil fertility a uniformity study be conducted. By a uniformity study is meant that the field will be laid out in plats of the size and shape that are to be used in the actual experiments, and the entire field will be sown to the same crop. The field should be handled in as uniform a manner as possible and the study continued for several seasons. The plats will be harvested and the data used to determine the variability of the different plats. The question is, "Are such trials useful ?" Some uniformity trials have been conducted and others are being conducted at the present time, and this paper is presented in the hope that those who have data from uniformity trials may be willing to present them. If this is done it may be possible to determine, in general, how useful uniformity trials are.

Some have criticized the value of uniformity trials on the basis that the yields of the plats may not be relatively the same from crop to crop, or that the plats will not react in the same manner after the experiment has been started. The vast amount of data presented by Harris and Scofield (5),[3] Parker and Batchelor (8), Garber, McIlvaine, and Hoover (4), and Garber and McIlvaine (3), showing the general tendency for the plats studied to react in a similar manner from year to year, should serve, in part at least, to meet this criticism. Even if there were little tendency to this association of yields, uniformity trials would serve a useful purpose in indicating whether all parts of the field chosen are suitable for laying down permanent or semi-permanent experiments. How many doubts, and possibly worries, could have been eliminated if data were available from two or three crops preliminary to certain experiments. So, in serving to point out parts of a field unsuitable for experimental purposes, uniformity trials will be useful.

Recently, added interest has been taken in the problem of uniformity trials, especially with reference to the interpretation of the results from such trials. Sanders (9), Eden (1), Murray (7), Vaidyanathan (12), and Summerby (11) have made valuable contributions to the subject following the method of analysis outlined by Fisher (2) but published first, as far as the author of this paper can determine, by Sanders (9). This method consists of making application of variance analysis and the determination of the covariance.

The method may be illustrated with unpublished data furnished by R. J. Borden of the Hawaiian Sugar Planters' Association, giving the yields obtained from the same plats for three different crops in uniformity trials of sugar cane. Sixteen plats have been used in this illustration, but the method may be applied to any number of plats.

[1]Paper No. 206, Department of Plant Breeding, Cornell University Agricultural Experiment Station, Ithaca, New York. Received for publication January 15, 1936.

[2]Professor of Plant Breeding.

[3]Figures in parenthesis refer to "Literature Cited", p.244.

The yields for 1931 and 1933, expressed in per cent, are given in Table 1.

TABLE 1.—*The application of the analysis of variance to data from uniformity trials, preliminary to the analysis of covariance.*

	Preliminary test				Total
	113	113	91	102	419
	102	109	105	102	418
	96	99	94	101	390
	98	99	94	82	373
Total....	409	420	384	387	1,600

General mean = 100

	Experimental test				Total
	103	110	92	113	418
	94	103	101	92	390
	103	99	94	99	395
	105	104	94	94	397
Total. ..	405	416	381	398	1,600

General mean = 100

Analysis of variance

Variation due to	Degrees of freedom	Sum of squares	Mean square or variance	Standard error
		Preliminary test		
Rows..	3	378.5	——	——
Columns	3	226.5	——	——
Error......... .	9	351.0	39.0000	6.24
Total.......	15	956.0	——	——
		Experimental test		
Rows.......	3	114.5	——	——
Columns	3	161.5	——	——
Error.... ..	9	336.0	37.3333	6.11
Total.	15	612.0	——	——

For convenience in the analysis, these plats have been arranged in the form of a Latin square, but other methods of arrangement may be followed. We may consider the test for 1931 as the preliminary test and the results for 1933 as the results from the actual experiment. Applying the methods for the analysis of variance, we have the results as given in the lower part of Table 1. The analysis shows that the standard error per plat for the preliminary test is 6.24 and for the experimental test 6.11.

We may now proceed to determine the covariance between the yields of the preliminary test and the experimental test in the

following way. The covariance is the mean product of the deviations of two variates, the deviations being measured from the respective means. The values and the deviations in the preliminary test will be designated x and those in the experimental test y, and we will consider first the results from the rows. The mean of the row totals in the preliminary test is 400 and the total yield of the first row for the preliminary test is 419. Therefore the x deviation is 19. For the next row it is 18; for the third row, which gives a total yield of 390, it is —10; and for the fourth row it is —27. The y deviations for rows from the experimental test are determined from the mean of the row totals in the experimental test in the same manner. The squares of the x and y values and the products of x and y are obtained as illustrated in Table 2. In a similar manner the squares of x and y and the products of x and y are obtained for the columns for both the preliminary and experimental tests, and also appear in Table 2. These squares and products are summed and divided by the number of contributing units, giving the values to be used in the analysis of variance.

In addition to the results for rows and columns, it is necessary to have similar values for the individual plats, or the total. These are obtained by taking each plat in one test and determining its deviation from the mean of all the plats for that test. For example, the mean of the preliminary test is 100 and the first plat in that test yields 113, so the x deviation is 13. For the corresponding y plat in the experimental test the yield is 103 and the mean of the experimental test

TABLE 2.—*Illustrating the method of determining covariance and the effect of regression on adjusted yields.*

	x	y	x^2	y^2	xy
		Rows			
	19	18	361	324	342
	18	—10	324	100	—180
	—10	— 5	100	25	50
	—27	— 3	729	9	81
Σ..............	—	—	1,514	458	293
Dividing by 4, the number of columns contributing to the individual deviations...........	—	—	378.50	114.50	73
		Columns			
	9	5	81	25	45
	20	16	400	256	320
	—16	—19	256	361	304
	—13	— 2	169	4	26
Σ..............	—	—	906	646	695
Dividing by 4, the number of rows contributing to the individual deviations.	—	—	226.50	161.50	173.75

TABLE 2.—*Continued.*

	x	y	x^2	y^2	xy
		Total			
	13	3	169	9	39
	13	10	169	100	130
	—9	—8	81	64	72
	2	13	4	169	26
	2	—6	4	36	—12
	9	3	81	9	27
	5	1	25	1	5
	2	—8	4	64	—16
	—4	3	16	9	—12
	—1	—1	1	1	1
	—6	—6	36	36	36
	1	—1	1	1	—1
	—2	5	4	25	—10
	—1	4	1	16	—4
	—6	—6	36	36	36
	—18	—6	324	36	108
....	—	—	956	612	425

Sums of Squares and Products

	Degrees of freedom	x^2	xy	y^2
Rows	3	378.50	73.25	114.50
Columns......	3	226.50	173.75	161.50
Error . .	9	351.00	178.00	336.00
Total.........	15	956.00	425.00	612.00

Analysis of Variance of Adjusted Yields

Variation due to	Degrees of freedom	Sum of squares	Mean square or variance	Standard error
Rows............	3	137.5175	———	——
Columns..............	3	43.5391	———	——
Error...............	8	245.7322	30.7165	5.54
Total...............	14	426.7888	———	——

is also 100, so the deviation for y is 3. The other values for x and y for the total are determined and together with their squares and products are shown in Table 2. These values are brought together in the summary. Subtracting the sums for rows and columns from the sum for the total, we obtain the residue, or the amount due to error.

From the values for x^2, y^2, and xy due to error we may determine the correlation coefficient, which will show the correlation between the yields of the plats for the different years. Having obtained the correlation coefficient, we may then determine the regression coefficient, b. Dividing the values for x^2 and y^2 by the degrees of freedom,

9, and extracting the square root, we obtain the standard deviations for x and y, which are 6.24 and 6.11, respectively. The correlation coefficient may then be determined from

$$r = \frac{\frac{\Sigma xy}{N}}{\sigma_x \sigma_y}$$

In this case N is the degrees of freedom, 9. Substituting the values for xy and for σ_x and σ_y, we have

$$r = \frac{\frac{178.00}{9}}{(6.24) \quad (6.11)} = .519$$

Substituting the necessary values in the regression equation for y on x,

$$y = r\frac{\sigma_y}{\sigma_x}x,$$

we have

$$y = .519 \frac{6.11}{6.24} x, \text{ or}$$

$$y = .508\,x$$

Since for the purposes of the analysis we are interested only in the regression of y on x, this may be obtained directly, letting b equal the regression coefficient, or

$$b = \frac{\Sigma xy}{\Sigma x^2}$$

Substituting the necessary values, we have

$$b = \frac{178.00}{351.00} = .507$$

The slight difference in the values obtained for b is due to the handling of the decimals.

We may now use this regression coefficient, .507, to correct the values for rows, columns, and total, and thus obtain a new standard error of the experiment after the effect of regression has been eliminated. Since b is the regression coefficient, the comparisons of adjusted yields are obtained from comparisons of $y - bx$.

Now

$$(y - bx)^2 = b^2x^2 - 2\,bxy + y^2$$

and to obtain the sum of the squares for any line from the values given in Table 2 under the title "sums of squares and products", the entries in the table are multiplied by b^2, $-2b$, and unity (the coefficients of x^2, xy, and y^2) and the products summed.

Multiplying the values of x^2, xy, and y^2 for rows, columns, and total by the values for b^2 (.257049), $-2b$ (-1.014), and 1, respectively, we have the results for the analysis of variance after the effect of regression has been eliminated, as given in the lower part of Table 2. Thus for rows we have

$$378.50 \times .257049 = 97.2930$$
$$73.25 \times -1.014 = -74.2755$$
$$114.50 \times 1 = 114.5000$$

The sum of these three products is 137.5175. The values for the columns and total are obtained in a similar manner. The degrees of freedom for rows and columns remain the same, but one degree of freedom has been used in determining the regression and therefore the degrees of freedom for the total are 14 rather than 15. Adding the sums of squares and degrees of freedom for the rows and columns and subtracting from the total, we have the residue and degrees of freedom as given in Table 2. Dividing the residue, 245.7322, by the degrees of freedom, 8, we have 30.7165, and extracting the square root we have 5.54 as the standard error of the experiment after the effect of regression has been eliminated. This may be compared with the standard error, 6.11, obtained before the effect of regression was removed.

The same result will be obtained if the predicted or calculated yields for y are obtained from $y - bx$ and these calculated yields used for the analysis of variance in the usual way. In this equation y is taken as the actual yield of the plat.

For example, for the first y plat we proceed as follows. The first x plat in the preliminary series yields at the rate of 113% of the mean yield, and the deviation from the mean is therefore 113—100, or 13. The adjusted yield for the first plat is obtained by substituting this value for x in the equation $y - bx$. The actual yield of the first y plat is 103, and we have $103 - (.507 \times 13)$, or 96.409, as the adjusted yield. The other adjusted yields are determined in a similar manner, and by applying the method of variance analysis we obtain the same standard error, 5.54, as by the shorter method in Table 2.

It should be pointed out that in using the equation $y - bx$ to obtain the adjusted yields, the degrees of freedom will be reduced from 15 to 14, since the value b has been obtained from the data. As b has been calculated from the values for error this reduction will be made in the degrees of freedom for error.

The foregoing illustrates the value of a preliminary trial in obtaining corrected yields for the plats and for determining a standard error for the experiment after eliminating the effect of regression. If the preliminary trial has been continued for several seasons or crops, the results for each year may be analyzed separately, or it is possible to combine the results for several years, determine the average, and use this average yield in making the analysis. To illustrate how this may be done, the yields for the same plats for the crop years 1929 and 1931 have been averaged and expressed in per cent, as shown in Table 3.

With these values the calculations are carried out exactly as explained before, and the sums of squares and products obtained for rows, columns, and total are given in Table 3. The regression, b, determined from x^2 and xy due to error, equals 216.25/250.50, or .863. From this regression, obtaining b^2 and $-2b$, the corrected values for the analysis of variance are determined and are given at the bottom of Table 3. It is seen that the standard error has been

TABLE 3.—*Application of the analysis of variance to yields adjusted on the basis of the yields of preceding crops.*

The average yields of the crops for 1929 and 1931 expressed in per cent

					Total
	106	110	95	108	420
	102	107	106	99	414
	97	97	95	99	388
	95	99	99	85	378
Total......	400	414	395	391	1,600

Experimental Test, 1933

	103	110	92	113	418
	94	103	101	92	390
	103	99	94	99	395
	105	104	94	94	397
Total......	405	416	381	398	1,600

Sums of Squares and Products

	Degrees of freedom	x^2	xy	y^2
Rows..........	3	306.00	86.50	114.50
Columns.	3	75.50	84.25	161.50
Error..........	9	250.50	216.25	336.00
Total........	15	632.00	387.00	612.00

Analysis of Variance of Adjusted Yields

Variation due to	Degrees of freedom	Sum of squares	Mean square or variance	Standard error
Rows.......... ...	3	193.1003	—	—
Columns........	3	72.3146	—	—
Error.............	8	149.3171	18.6646	4.32
Total...........	14	414.7320	—	—

reduced to 4.32 by combining the yields of the two preliminary trials.

Recently, Bartlett and Wishart have made certain suggestions as to refinement of methods of adjusting yields and these suggestions have been applied by Snedecor (10) in a recent publication. Fisher (2) in the fifth edition of his book does not follow these suggested methods but does add a further refinement to the method he published earlier. In this connection he says, "The value of b used in obtaining the adjusted yields is a statistical estimate subject to errors of random sampling. In consequence, although the quantities $y - bx$ are appropriate estimates of the corrected yields, they are of varying precision; the sums of their squares in the lines of the table

from which b has not been calculated do not therefore supply exact material for testing the homogeneity of deviations from the simple regression formula. This test we should wish to make if real differences of treatment had been given to our plots, ..."

Instead of adjusting all values on the basis of the regression, b, obtained from the estimate of error, Fisher adjusts the values for total and error on the basis of their own regression by deducting from $S(y^2)$ the quantity $(Sxy)^2/S(x^2)$. The adjusted value for treatment is then obtained by deducting the reduced value for error from the reduced value for total. This method of adjustment is applied to the sums of squares and products for the data in Table 2, omitting those for columns, and the results are given in Table 4. For purposes of illustration the rows may be considered as treatment.

TABLE 4.—*Adjustment of values from Table 2 according to method by Fisher.*

	Degrees of freedom	Sums of squares and products			Degrees of freedom	Reduced values	Mean square
		x^2	xy	y^2			
Rows . .	3	378.50	73.25	114.50	3	118.2338	39.4113
Error	9	351.00	178.00	336.00	8	245.7322	30.7165
Total	12	729.50	251 25	450.50	11	363.9660	———

For the reduced value for total we have

$$450.50 - \frac{(251.25)^2}{729.50} = 363.9660$$

The adjusted value for error is obtained in a similar manner, and it is noted that in each case one degree of freedom is lost. Subtracting the adjusted value and degrees of freedom for error from those for total, we have three degrees of freedom and a reduced value of 118.2338 for rows or treatment. The mean square of this reduced value is to be compared with the mean square of the reduced value for error. This refinement of method should be given consideration especially where treatments are concerned, and the methods of Bartlett and Wishart as applied by Snedecor (10) may also be of value in such cases.

Sanders (9) has shown that the variance of adjusted yields may also be calculated from the formula $V_{y.x} = V_y - \frac{(Cov_{xy})^2}{V_x}$.

In this formula $V_{y.x}$ is the variance of the adjusted yields, V_y and V_x are the variance values for y and x, and Cov_{xy} is the mean of the product deviations of x and y measured from their respective means. The value resulting from this formula is corrected for one degree of freedom used in obtaining the regression value. The increase in precision obtained as the result of using the previous records is then given by $\frac{V_y}{V_{y.x}}$.

Using the data from our first problem, we have from Tables 1 and 2

$$V_y = 37.3333 \qquad Cov_{xy} = \frac{178.00}{9} = 19.7778 \text{ and}$$
$$V_x = 39.0000$$

$$V_{y.x} = V_y - \frac{(Cov_{xy})^2}{V_x} = 37.3333 - \frac{(19.7778)^2}{39.0000} = 27.3035$$

Correcting for the one degree of freedom used in the regression, we have

$$V_{y.x} = \frac{9}{8} \times 27.3035 = 30.7164$$

as the variance of the adjusted yields. The precision is given by

$$\frac{V_y}{V_{y.x}}, \text{ or } \frac{37.3333}{30.7164} = 1.22.$$

The increase in precision gained by using the average of the preliminary yields for 1929 and 1931 is given by $\frac{37.3333}{18.6646} = 2.00$

This shows a very satisfactory increase in precision.

Another example from 48 plats of sugar cane, using the results from only one preliminary crop, showed some increase in precision. The precision constant is only 1.52 in this case, but even so, if long-time fertilizer trials are to be undertaken, it suggests that it may be advisable to continue the uniformity test one more year at least.

Data from the Illinois Agricultural Experiment Station supplied by Hopkins, Readhimer, and Eckhardt (6) with corn as the preliminary crop and clover as the experimental crop, have been studied and a precision factor of 1.41 obtained. Again, with some of the data presented by Harris and Scofield (5) with alfalfa as the preliminary crop and corn as the experimental crop, a precision factor of 1.46 was obtained.

Sanders (9), working with annual crops, has shown by this method of analysis that for one field the precision of an experiment would be increased by nearly 150% if the regression on the mean yield of the three previous years were used. Sanders says, "In this instance the gain is very considerable, and it is possible that under certain circumstances (e. g. with a restricted area, or where little assistance was available at any one time) it might repay the labour of 3 years uniformity trials, even though it would increase the work fourfold and the precision but little more than threefold: such a result must not however be expected in all cases . . . ." The other field studied by Sanders showed no constancy in yield.

Eden (1), working with tea, made application of this method and found that the standard error per plat for the experimental field without considering the regression was 10.93, while the standard error fell to 4.19 when the regression was considered. He concludes, "In terms of the precision index, the experiment with the regression is 6.81 times as accurate as that without; since the replication is fourfold, the corrected figures give an accuracy which could only be

expected from the crude data with a replication of twenty-seven and with the use of the regression this involves only twice the labour."

Murray (7), working with rubber and assuming five replications, found that considerable reduction was obtained by making use of the preliminary cropping records. The precision index was found to be 3.74 and he states, "In other words, if the year 1927 were to stand alone, the number of replications necessary to achieve the same degree of accuracy would be 5×3.74, or approximately 19." Murray emphasizes the importance of considering the preliminary data, as follows: "A practical point to be noted is that the regression is a more effective means of reducing error than the removal of positional variance; the elimination of rows and columns has only reduced the variance from 10,024 to 7,421, whereas the regression based on the total sums of squares (i. e. ignoring rows and columns) reduces it to 1,754. This suggests that results of some value can be obtained with rubber where previous records are known, but where the arrangement of the plots does not permit elimination of the positional effect." He concludes, "It is concluded that not only has the method of correction been of value in the particular instance investigated, but that a uniformity trial utilized in this way should be of practical value in any major field experiments with rubber."

Vaidyanathan (12), using data from tea plats, emphasizes the importance of making use of preliminary data when available and states, "From such an analysis of variance of preliminary yields, it is possible, for example, to know whether there is a significant variance in yields in 'rows' and 'columns' or again whether 'rows' and 'columns' themselves significantly differ. If it so happens that 'rows' show significant increase over 'columns', then the block arrangement of plots along 'columns' should be preferred and *vice versa*. Or again if both 'rows' and 'columns' show very high variances as compared to randomness, the size of the block should be appreciably reduced and the number of replications correspondingly increased. Thus the analysis of data of preliminary yields into 'block' variance and 'random' variance can always indicate an improved method of lay-out." With the data used, Vaidyanathan found that the improvement in precision resulting from the use of the preliminary crop yields was increased nearly 16 times and concludes, "Thus it is seen that where preliminary yields of experimental plots can be secured, it seems advantageous to explore them fully and make valid use of them. By using such data, not only is an 'improved' lay-out possible but there is a possibility of securing a 'greater' precision on which a more equitable comparison of 'treatments' should necessarily depend."

Summerby (11) says in conclusion to his study, "Under the conditions of this experiment the use of preliminary uniformity trials for the purpose of adjusting yields of subsequent experiments by regression is only rarely as effective in increasing precision as is the use of the same amount of land and labour in replicating the experiment in the year of the trial. Preliminary uniformity trials may, however, be useful in determining the plotting plans that will give the greatest precision. They may also prove useful in eliminating areas that are unsuited for experimental purposes."

Garber and McIlvaine (3) state, "The correlations presented ..... show very definitely that an appreciable amount of the total variation in the corn yields may be accounted for by the different levels of natural productivity that existed among the plats when the rotation experiments were begun, as measured by a uniformity crop. In view of this fact the experimental error might be reduced still further by analyzing the covariance between the yields of the uniformity crop and the corn yields obtained subsequently."

Fisher (2) states, "Analysis of covariance on successive yields on uniformly treated land shows that the value of the experiment is usually increased, but seldom by more than about 60 per cent, by a knowledge of the yields of the previous year. It seems therefore to be always more profitable to lay down an adequately replicated experiment on untried land than to expend the time and labour available in exploring the irregularities of its fertility."

In the light of recent studies, however, and especially from the results of Murray (7), where he found that regression or the use of preliminary data is a more effective method of reducing error than the removal of positional variance, such as blocks, it must be admitted that there are times when this method of using preliminary crop yields will be a very valuable addition to our experimental technic.

At the present time the data studied indicate that greater gains in precision are obtained from crops like tea and rubber, or in other words, where the plats have the same plants from year to year. This suggests that certainly for long-time experiments where orchard, forest, or similar crops are to be the experimental material, it would no doubt be of benefit to conduct some preliminary cropping trials.

For annual crops more data are needed to settle the question, but it would seem that certainly for such experiments as long-time crop rotation and soil fertility studies, preliminary cropping will be of value. If no gain in precision is obtained, at least the preliminary cropping should aid in improved lay-out. The fact that, for most of the cases studied to determine the permanency of plat variability, it has been found that there is a relation from year to year, would indicate that this problem should be investigated further. In other words, our present stand should be that of seeking further information rather than to conclude either that the method will always lead to greater precision or that the system of preliminary cropping will be of little value. Certainly, for indicating those parts of a field that should not be used for experiment and for suggesting a better lay-out, preliminary cropping will be useful, and for some fields and crops at least the data from preliminary cropping will lead to greater precision.

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THE COMBINING ABILITY OF INBRED LINES OF GOLDEN BANTAM SWEET CORN[1]

I. J. JOHNSON AND H. K. HAYES[2]

WHEN only a few inbred lines of corn are available the usual method of determining how they can be used most advantageously is to make all possible combinations between them and select for commercial production the single, three-way, or double crosses that prove the most satisfactory. When many inbred lines are available it has proved desirable to test their combining ability and discard those that give low-yielding crosses on the average. The first method of determining combining ability consisted of a series of crosses of each inbred with 10 or 12 inbred lines used as testers. In 1932, Jenkins and Brunson[3] presented data to show that an open-pollinated variety could be used as a tester to determine the relative combining ability of inbred lines. Significant and fairly high correlations were obtained between the mean yields of inbred lines in several single crosses and the average combining ability of these same lines in top crosses. This has led to the use of top crosses as a means of selecting inbred lines with satisfactory combining ability.

The present study was made to determine the reliability of top crosses as a means of determining the combining ability of inbred lines of sweet corn. A study was made also of the relation between characters of inbred lines and their F_1 top crosses.

MATERIALS AND METHODS

In 1934, a group of 39 inbred lines, of which 31 were obtained from an eight-rowed canning type of Golden Bantam and 8 from a cross of two inbred lines, were selected for this study. The lines had been inbred for 6 to 12 years and were the most desirable lines remaining from the standpoint of vigor and other desirable plant characters. Since the majority of these lines, like those obtained from the earlier inbreeding studies with Golden Bantam lines at Minnesota, were sufficiently vigorous to be be used in commercial single crosses, these lines if crossed in all possible combinations to find the most desirable hybrids, would have necessitated making and testing 741 single crosses [½n (n–1)]. With a few exceptions, each of these lines was top crossed to the parental Golden Bantam variety, to Del Maiz, a medium-maturing, 10- to 16-rowed yellow sweet corn developed by the Minnesota Valley Canning Company, Le Sueur, Minnesota, and to a Del Maiz inbred line. The Golden Bantam and Del Maiz top crosses were separated into two groups and grown in single-row plats with three randomized replications at University Farm, St. Paul, Minn. The field distribution of the two groups was also randomized. The Golden Bantam and Del Maiz top crosses and the single

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[2]Assistant Professor and Chief, respectively.

[3]JENKINS, MERLE T., and BRUNSON, ARTHUR M. Methods of testing inbred lines of maize in cross bred combinations. Jour. Amer. Soc. Agron., 24:523–530. 1932.

crosses with the Del Maiz inbred line were grown in single-row plats with two randomized replications at Le Sueur, Minn.

Eleven of the 39 lines obtained by selfing normal Golden Bantam were crossed in all possible combinations to make 55 single crosses. These were grown at University Farm in single-row plats with three replications in randomized blocks. The inbred lines used in the character study were grown in single-row plats with one plant per foot in two randomized replications at University Farm. The data discussed in this paper on the hybrids are based on the yield of cut corn from 3-stalk hills surrounded by hills of corn. Yield of mature ears and notes on several plant characters of the inbred lines were obtained from a character study of the inbred lines.

EXPERIMENTAL RESULTS

The data from this study will be presented and discussed in three separate parts, as follows: (1) The correlation between the yield of single crosses and the average yield of lines in all top crosses and in several single crosses; (2) the correlation between yields obtained from top crosses with the parental variety, with an unrelated variety, and with an unrelated inbred line; and (3) the correlation between several characters of the inbred lines and their average yield in top crosses and with an unrelated inbred line.

CORRELATION BETWEEN TOP CROSS AND SINGLE CROSS YIELDS

Since 11 of the inbred lines used in the top cross study had been crossed in all possible combinations, it was of interest to determine the correlation between the yield of these lines in top crosses and in F_1 single crosses. The 11 lines varied in their average top cross yield from 170 to 253 grams of cut corn per hill. A study of the combining ability of the lines was made in two ways, first, by the correlation between the yields of the 55 single crosses and the average top cross yield of the two parents, and second, by the correlation between the yields of the single crosses and the average yield of the two parents in 9 other single crosses. The results of these studies are given in Table 1.

TABLE 1.—*Comparison between the top cross yields and the average single cross yields as a means of measuring the combining ability of inbred lines.*

Characters correlated	n	Correlation coefficient
Average of parental lines in top crosses and single cross yields	55	.4748±.1044
Average of parental lines in 9 single crosses and single cross yields	55	.6991±.0689
Average yield of 11 lines in single crosses and in top crosses	11	.7835±.1221

This phase of the present study is of particular interest since in the final analysis the proof of the validity of any method of determining the combining ability of inbred lines lies in the actual yields of hybrids made between them. From the correlations given in Table 1, it is evident that a fairly close relationship exists between

the mean yield of the parental lines in top crosses and the actual F_1 yield between them (r = .4748). Inbred strains producing high-yielding top crosses should then be expected to give the highest yielding single crosses. The relationship between the mean yields of the parental lines in nine single crosses to the yield of the F_1 single cross between them is likewise fairly close (r = .6991). The difference between these two coefficients is 1.8 times their standard error, and consequently it may be assumed that the estimation of combining ability of inbred lines by means of top crosses is about as accurate as their estimation on the basis of their mean yields when crossed with nine other lines used as testers. A high correlation coefficient of .7835 was obtained between the top cross yields of the 11 lines and the average yield of the 11 lines in their 10 single crosses.

In the final comparison made between the yields of the lines in top crosses and in single crosses, the 11 lines were classified into four groups on the basis of their average top cross yield. The lines in group 1 gave top cross yields of 170 to 194 grams per hill; those in group 2, 195 to 219 grams; those in group 3, 220 to 244 grams; and those in group 4, 245 to 269 grams per hill. The distribution of the single crosses made between inbred lines with different levels of combining ability as determined by top crosses is shown in Table 2. From an inspection of the yields from the various groups of crosses it is evident that the poorer combining lines crossed among themselves, i.e., group 1 x group 1 and group 1 x group 2, failed to produce high-yielding single crosses. Crosses made between poor combining lines and good combining lines, i.e., group 1 x groups 3 and 4 and group 2 x groups 3 and 4, gave a few good single crosses on the basis of the average yield of 257 grams per hill from the standard open-pollinated parental Golden Bantam. Crosses between the

TABLE 2.—*Distribution of yields from Golden Bantam single crosses made between inbred lines classified into four groups on the basis of their top cross yields.*

Groups crossed	No. of crosses	Distribution of single cross yields in grams per hill											Actual average, grams
		130	160	190	220	250	280	310	340	370	400	430	
Group 1 x Group 1	3	1	1	1	–	–	–	–	–	–	–		161
Group 1 x Group 2	3	2	–	1	–	–	–	–	–	–	–	–	147
Group 1 x Group 3	15	–	1	–	4	5	3	2	–	–	–	–	250
Group 1 x Group 4	6	–	–	–	1	3	1	1	–	–	–	–	260
Group 2 x Group 3	5	–	–	1	1	2	1	–	–	–	–	–	237
Group 2 x Group 4	2	–	–	–	–	1	1	–	–	–	–	–	274
Group 3 x Group 3	10	–	–	–	1	–	3	2	2	1	–	1	315
Group 3 x Group 4	10	–	1	–	–	1	3	4	–	1	–	–	284
Group 4 x Group 4	1	–	–	–	–	–	–	1	–	–	–	–	305

Group 1—cultures 4, 5, 9
Group 2—culture 10
Group 3—cultures 1, 2, 3, 8, 11
Group 4—cultures 6, 7
Top cross yield = 170 to 194 grams per hill.
Top cross yield = 195 to 219 grams per hill.
Top cross yield = 220 to 244 grams per hill.
Top cross yield = 245 to 269 grams per hill.

better combining lines, i.e., group 3 x groups 3 and 4 and group 4 x group 4, gave most of the really superior single crosses. On the basis of this test, very little superior germ plasm would have been lost by discarding the inbred lines in groups 1 and 2, the poorer combining lines in the top cross test. The average yield of all crosses from the two higher combining groups of lines, i. e., group 3 and group 4, was found to be 301 grams per hill. By the use of this value as a criterion for determining the distribution of high and low yielding crosses from the different groups of lines the general summary in Table 3 was obtained.

TABLE 3.—*Distribution of single crosses above and below the mean yield of 301 grams per hill obtained from all single crosses made between high combining inbred lines.*

Groups crossed	Number of single crosses		Average yield of group crosses grams
	Below average	Above average	
Group 1 x group 1 and 2	6	0	154
Group 1 x group 3 and 4	18	3	253
Group 2 x group 3 and 4	7	0	245
Group 3 x group 3	4	6	315
Group 4 x group 3 and 4	5	6	285

Of the 15 single crosses whose yields exceeded the average from the high combining lines in groups 3 and 4, only 3 were produced from low combining lines and 12 from the better combining lines. These results, together with the correlation coefficients given in Table 1, tend to show that the top cross test as a means of discarding the poor combining lines may be used without a serious loss of high yielding hybrids. It should be recognized, however, that the low combining lines do occasionally produce high-yielding hybrids—particularly when crossed with high-combining inbred lines.

RELATION BETWEEN TOP CROSSES MADE TO PARENTAL VARIETY, TO AN UNRELATED VARIETY, AND TO AN UNRELATED INBRED LINE

The relationship between the yields of the inbred lines in several top crosses determined by means of correlations between the different crosses and correlations between yields at the two locations is given in Table 4.

While several of the correlation coefficients are significant, they are rather low, on the average. Correlations of .2798 and .1761 were obtained, respectively, for yields of top crosses of Golden Bantam at University Farm and Le Sueur and Del Maiz at University Farm and Le Sueur. It should be remembered that three replications for each cross were used at University Farm while only two were used at Le Sueur.

The correlation between yielding ability in all trials at University Farm with all trials at Le Sueur gives an opportunity to compare

TABLE 4.—*Relation between yield of top crosses made with inbred lines of Golden Bantam to the parental variety, to unrelated Del Maiz, and to Del Maiz inbred culture 1 in trials made at University Farm and Le Sueur, Minn.*

Yield of top crosses correlated	Location of test	Correlation coefficient
Golden Bantam with Del Maiz...	University Farm	.3009
Golden Bantam with Del Maiz...	Le Sueur	.3541
Average Golden Bantam with average Del Maiz... .. .	University Farm and Le Sueur	.4214
Golden Bantam with culture 1 .	Le Sueur	.2019
Del Maiz with culture 1........	Le Sueur	.0110
Golden Bantam...............	University Farm and Le Sueur	.2798
Del Maiz.	University Farm and Le Sueur	.1761
All trials at University Farm with all trials at Le Sueur*........	———	.3633
Significant r (P = .05).........	———	.3246

*Crosses with culture 1 omitted.

the combining ability of inbred lines in two top cross studies (six plats in all) at University Farm with that at Le Sueur (four plats in all). This coefficient was .3633 while significant r is .3246. The yields of Golden Bantam and Del Maiz top crosses at University Farm and Le Sueur were correlated to the extent of only .3009 and .3541, respectively, while combining the top cross yields of the two varieties at University Farm and Le Sueur gave a coefficient of .4214. These results indicate that too few replications were used in these studies to make it possible to draw accurate conclusions regarding the comparative desirability of Golden Bantam and Del Maiz as tests of combining ability of inbred lines of Golden Bantam. Del Maiz culture 1 was selected because it gave desirable crosses for canning purposes. This single inbred line proved very unsatisfactory to test the combining ability of these inbred lines.

The results of these studies indicate that rather careful field trials are needed to determine combining ability. If it is desired to obtain this information in a single season, tests should be made in several localities and sufficient replications, many more than in this study, should be made to insure accurate results.

CHARACTERS OF INBRED LINES RELATED TO TOP CROSS YIELDS

The inbred lines were grown in two separate series of randomized blocks and data were taken on various characters. From an analysis of variance the inbred lines were found to be significantly different in the following seven characters: Yield, ear length, number of suckers, stalk diameter, pulling resistance, leaf area, and plant height. Simple product moment correlation coefficients were computed to determine the relationship between these characters in inbred lines and the combining ability of inbred lines in top crosses.

The data from this study, given in Table 5, show that in the simple correlations stalk diameter and leaf area both show a positive and significant relationship to combining ability of the inbred lines. Ear

length and plant height show a slight positive relation to the top cross yield and number of suckers on the inbred plants a slight negative relation to yield of the top cross. The yield of the inbred lines and their pulling resistance show very little relationship to the yield of the top cross.

TABLE 5.—*Relation between characters of the inbred lines (2–8) and yield of the inbred lines in top crosses (1) as measured by simple and partial correlation coefficients.*

Characters of the inbred lines	Simple correlation coefficients	Partial correlations	
		Characters correlated	Correlation coefficients
Yield (2)	—.0170	r12.345678	.1946
Ear length (3)	.2770	r13.245678	.4483
No. of suckers (4)	—.2619	r14.235678	—.4648
Stalk diameter (5)	.3781	r15.234678	.4461
Pulling resistance (6)	— 1070	r16.234578	—.0883
Leaf area (7)	.3964	r17.234568	.1048
Plant height (8)	2791	r18.234567	.0194
Significant r (P = .05)	.3165	———	.3444

In the partial correlation study, the relation between the top cross yield and each of the seven characters of the inbred lines was determined by holding constant all of the other six inbred characters. The partial correlations also give in Table 5 show that ear length and stalk diameter of the inbreds are significantly and positively related to the combining ability of the inbred lines measured by their top cross yields. The number of suckers per plant while nearly significant in the simple correlations is significant and negatively associated with the top cross yield in the partial correlations. Average number of suckers was studied in the 55 single crosses discussed previously and a correlation coefficient computed between yield of F_1 crosses and number of suckers. The coefficient obtained, .0035, shows no association. These results in eight-rowed Golden Bantam crosses are different than those reported by Jones, *et al.*[4] On the basis of this coefficient the degree of suckering in inbred lines and the hybrids between them is not an important factor in determining yielding ability. The relation between the yield of the inbreds and the top cross yields is somewhat greater than that found in the simple correlation but considerably below the 5% point in significance. Pulling resistance, leaf area, and plant height show only a very small relation to the top cross yield as measured by the partial correlations.

In general, none of the characters studied shows a striking relation to the top cross yield. In fact, the multiple correlation between the the top cross yield and all seven inbred characters of .4653 strongly suggests that a large part of the characters that determine combining ability of the inbred lines have not been accounted for in this study.

[4]JONES, D. F., SINGLETON, W. R., and CURTIS, L. C. The correlation between tillering and productiveness in sweet corn crosses. Jour. Amer. Soc. Agron., 27:138–141. 1935.

This may be due to the relative inaccuracy of the data on inbred lines when only two replications were grown.

SUMMARY

In a study of the combining ability of inbred lines of Golden Bantam sweet corn made at University Farm, St. Paul, Minn., 39 inbred lines were top crossed to the parental variety, to an unrelated variety of Del Maiz sweet corn, and to a Del Maiz inbred line. The inbred lines were also grown and measurements were made of several of their characters, including yield. Eleven of the inbred lines used in the top cross study were crossed in all possible combinations to produce 55 single crosses.

The study of the relation between top cross yields and single cross yields between 11 inbred lines shows that inbred lines that give high yields in top crosses are more likely to produce the best single crosses than the inbred lines that give low yield in top crosses A few good single crosses were obtained between lines that gave high x low yield in top crosses. In a comparison between the average top cross yield of the two parental lines and the single cross between them and in a comparison between the average yield of the two parental lines in nine single crosses and the single cross between them, fairly high correlation coefficients were obtained (r .4748 and r .6991). The difference between these two coefficients is not significant and suggests that the combining ability of inbred lines determined by top crosses and by several tester lines are of nearly equal value in isolating the best combining lines.

A study was made to determine the relationship between the yields of top crosses to the parental variety, to an unrelated variety, and to an unrelated inbred line. The trials were conducted at two locations in the state. Although the correlation between the top cross yields to the parental variety and to unrelated varieties was low, the correlation between the same crosses at the two locations was also low. These results indicate that too few replications were used in this study to draw accurate conclusions on the comparative desirability of the related and unrelated varieties as a test of combining ability of inbred lines. These results also suggest the need for many replications, preferably at several locations, to determine accurately in a single year the combining ability of inbred lines by the use of the top cross test.

In a study of the relationship between characters of the inbred lines and the yield of the lines in top crosses made by means of simple and partial correlations, a few significant but not very high correlations were obtained. Ear length and stalk diameter of the inbred lines tend to be positively associated with top cross yields and number of suckers per plant negatively associated with top cross yields. The yield of the inbred lines was not significantly associated with combining ability in top crosses either in simple or partial correlations.

NOTES

A NURSERY THRESHER FOR SORGHUM HEADS

A NURSERY thresher particularly adapted to threshing individual heads of sorghum has been constructed at the U. S. Dry Land Field Station, Lawton, Okla. Two views of it are shown in Fig. 1. Approximately 2,000 individual heads have been threshed successfully in the past two seasons. Two men can thresh, clean, bag, and label 500 individual heads in 8 hours. The thresher also has been used for nursery rows of wheat and bulk lots of sorghum. It is relatively inexpensive and so simple that any good mechanic can build it.

The thresher is of a box type, designed for self-cleaning, by eliminating projections where grain might lodge and by providing for all material to drop into the grain drawer. The inside is lined with tin that forms a funnel leading to a grain drawer at the bottom. The bottom of the funnel, 6 x 8 inches, is large enough to avoid clogging. The grain drawer is 12 x 8 inches and 4 inches deep.

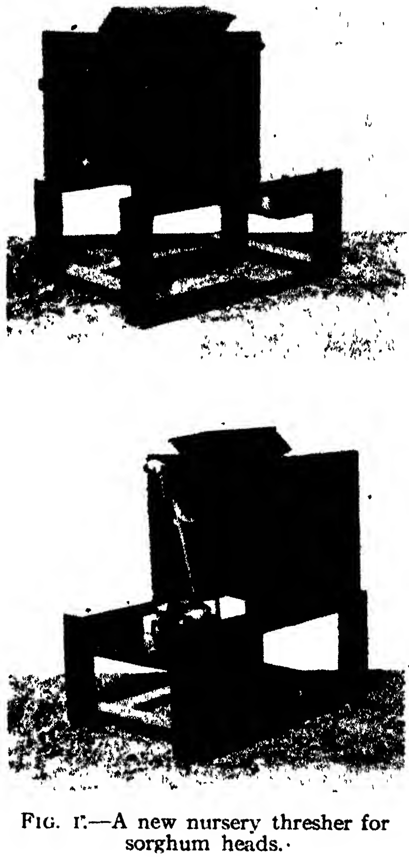

FIG. 1.—A new nursery thresher for sorghum heads.

The thresher frame and base are built of 2 x 4 inch lumber. The sides of the box are 1 x 3 inch tongue and groove boards. The outside dimensions of the frame are 21 inches x 17 inches, and 19 inches high. The feeding chute extends above the top of the box 1½ inches at the front and 2½ inches at the rear. It sits at approximately a 45-degree angle to permit easy insertion of the heads. A hinged lid on the top of the chute with a small notch in the front for the sorghum stem is closed to prevent loss of grain while the head is being threshed.

The cylinder was made from a block of oak 10 inches long that was bored lengthwise and a 7/8-inch steel shaft inserted and secured. The oak cylinder was then turned on a lathe to a diameter of 4 inches. A large metal washer was fastened with screws to each end of the cylinder to prevent splitting of the wood.

The cylinder teeth were made from ¼ inch lag screws 2¼ inches long. Holes 3/16 inch in diameter and 1 inch deep were bored in the cylinder. A small quantity of powdered resin to help hold the screws was poured into each hole. After the screws were in place the heads were cut off with bolt cutters, leaving teeth about 1 inch in length. The teeth were placed 2 inches apart in rows lengthwise of the cylinder and the rows were ½ inch apart. The teeth, in alternate rows, were offset 1 inch to center them in the spaces between the teeth in adjacent rows. There were 24 rows of teeth, with 5 teeth to the row.

The shaft ran in bearings bolted on the frame work of the thresher. The inside width of the thresher, 12 inches, allows a 1-inch clearance at each end of the 10-inch length cylinder to avoid clogging.

The concave was made of a 2 x 8 inch piece of oak on which a concave surface was chiseled. The concave was placed about 1¼ inches from the cylinder so that the ends of the two sets of teeth overlapped about 3/8 inch and was closely fitted and securely fastened to the sides of the thresher to prevent the lodging of grain. The spacing and arrangement of the 45 concave teeth was the same as those on the cylinder.

The thresher is mounted crosswise on a base 14¼ inches high, 33 inches long, and 21 inches wide. An electric motor is mounted on the base at the side of the thresher. The entire unit, weighing 130 pounds, can be moved without disturbing the belt adjustment. The thresher can be operated by a ¼ to ½ horse-power motor, at a speed of about 1,000 R.P.M.

In threshing, the sorghum head is fed into the cylinder gradually and then withdrawn. The grain and chaff fall into the drawer, are screened through ¼ inch hardware cloth to remove the larger particles, and then poured in front of an electric fan to blow out the chaff. Recleaning seldom is necessary.

For convenient handling of the sorghum heads the stems should be at least 8 inches long.—R. O. SNELLING, *Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Lawton, Okla.*

CYTOLOGY OF CEREALS

THE attention of agronomists, and especially plant breeders, is called to a review of literature pertaining to the cytology of the cereals, including wheat, rye, barley, and oats, made by Hannah C. Aase in BOTANICAL REVIEW, 1 : 467–496, 1935.

A comprehensive review is made of 125 articles most of which have been published since the author's original paper (Research Studies, State Coll. Wash., 2 : 3–60. 1930). A general summary table of chromosome conjugations in F_1 of cereal hybrids is given based on more than 300 crosses, involving more than 150 different species combinations.

Phylogenetic relationships are suggested in a diagram showing allopolyploidy in wheat.—A. M. SCHLEHUBER, *State College of Washington, Pullman, Wash.*

A SPECIAL SLIDE RULE FOR RAPID CALCULATION OF TIME FOR THE WHEAT MEAL FERMENTATION TIME TEST

CONSIDERABLE time is spent in the usual method of calculating the number of minutes that elapse between any two periods of the day. This task becomes very tedious and time consuming, especially when the "time" must be calculated on some 150 or 200 individual fermentation time tests which are carried out daily in connection with quality studies in the wheat breeding program at the Purdue University Experiment Station. Errors can easily be made and often overlooked since it is very easy to add or omit 60 minutes from the total. As a result, the writers were interested in simplifying the calculating of "time" and yet secure the results with speed and accuracy. Calculating tables were found to be too large and clumsy. Since slide rules are used more and more in simplifying calculations, it seemed that special scales might be developed and mounted on a slide rule, and thus the "time" rapidly calculated. Therefore, two special scales ("A" and "B") were developed and mounted on a slide rule as shown in Fig. 1.

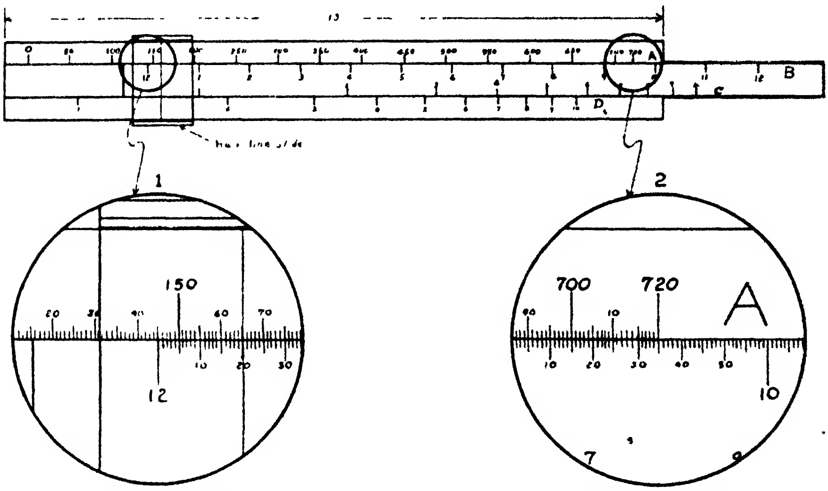

FIG. 1.—A special slide rule used in calculating the total number of minutes between any two periods of the day.

On scale "A" the minutes for a 12-hour period are summed up at 10-minute intervals up to 720 minutes. Scale "B" indicates a linear arrangement of the hours and minutes prevalent during a 12-hour day as ordinarily given on the face of a clock. By means of these two scales, results can be obtained in a few seconds which would require minutes by the usual method.

The following example will illustrate the use of the special slide rule. Suppose one wished to determine the total number of minutes between 9:35 a. m. and 12:20 p. m. Move the slide to the right so that 9:35 on scale "B" is at the right end of scale "A" or at 720,

as shown in Fig. 1. Set the runner so that the hair line is exactly at 12:20 p. m. (scale "B"). The answer, 165 minutes, is obtained at the intersection of the hair line on scale "A". In much the same way the total number of minutes can be determined between any two periods within a 12-hour day.

The regular "C" and "D" scales, used in multiplication and division with standard slide rules, are also included in the above special rule.—W. W. WORZELLA and C. B. JUDAY, *Purdue University Agricultural Experiment Station, Lafayette, Indiana.*

ERRATUM

ON page 72, line 2, of the January, 1936, number of this JOURNAL, in an article on "Cotton Varieties Recognized as Standard Commercial Varieties", substitute the name of E. F. Cauthen for B. C. Rhyne. On page 76 of the same article, second line from the bottom, the sentence reading, "L. L. Ligon, cotton breeder for the Oklahoma Experiment Station, made the original selection and has continued plant selection in the variety each year since 1914", should read, "Glen Briggs, then cotton breeder for the Oklahoma Experiment Station, made the original selection. L. L. Ligon has continued plant selection in the variety since 1925."

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THE EFFECT OF CORN SMUT ON THE YIELD OF GRAIN IN THE SAN JOAQUIN VALLEY OF CALIFORNIA[1]

FRANCIS L. SMITH[2]

CALIFORNIA'S corn crop is grown for two purposes, green table corn and grain corn. Roughly, a little over half of the corn acreage is utilized as a grain crop. In 1933, there were 100,000 acres of corn in California, of which 53,000 was grain corn, producing 1,696,000 bushels (13).[3] According to the 1935 census,[4] there were 59,716 acres of corn in California, 38,450 acres, producing 1,429,093 bushels, being grown for grain.

Grain corn in California is largely used as chicken feed. About 4,931,000 bushels were imported into California from abroad in 1935.[5] Annually some 250,000 to 400,000 bushels are shipped in from other states We therefore produce less than one-fourth of the corn used in the state.

Most of the state's grain crop is grown in the deltas of the San Joaquin and Sacramento rivers. The 1935 census reported San Joaquin County's grain corn as 21,221 acres, 952,820 bushels, or approximately two-thirds of the state's production.

Each year growers in these areas suffer some losses from corn smut, *Ustilago zeae* (Beckm.) Ung. In 1935 an effort was made to measure the loss that could be attributed to this disease. The variety generally grown throughout the delta region is known locally as King Philip, or more accurately, King Philip Hybrid. This is not to be confused with King Philip, an 8-rowed, red-grained flint corn. This variety was developed about 1900 from a field cross between Reid's Yellow Dent and King Philip, followed by a number of years selection by W. C. Sheldon, a farmer near Elk Grove, California. The grain is not a typical flint nor is it a dent, but is somewhat intermediate in

[1]Contribution from the Division of Agronomy, University of California, Berkeley, Calif. Received for publication January 16, 1936.
[2]Junior Agronomist.
[3]Figures in parenthesis refer to "Literature Cited," p. 265.
[4]Department of Commerce, Bureau of Census. Preliminary report of Farm Census for California. Released Jan. 2, 1936.
[5]Estimates furnished by Dallas W. Smythe, Assistant in Agricultural Extension and Associate on the Giannini Foundation, California Agricultural Experiment Station.

texture between the two. Both types have been isolated from the variety following selfing.

REVIEW OF LITERATURE

Estimates of losses in the United States due to corn smut are made annually. These estimates by states usually vary from 0 to 15%. For the period 1920–29 the estimated losses in California were 7.7% (12). Of course these estimates are subject to a large number of personal opinions.

A number of careful studies have been made on the effect of smut in reducing yields. Garber and Hoover (2) found that smut infections in West Virginia did not appreciably reduce yields, although smutted plants were more often barren (38%) than nonsmutted (19.8%). Recently the same authors (3) have reported some statistical studies on the incidence of smut in commercial varieties, F_1 crosses, and selfed lines. They reiterate that smut in West Virginia does not greatly reduce yields. The greatest loss they found was in early maturing F_1 crosses with smut infections on the neck of the plants in their 1932 cultures. This loss was 17.1%. Even with smut galls as large or larger than a hen's egg no significant reduction in yield of grain or forage was noted if the smut galls were below the ear. Infections above the ear reduced yields in 1933. Barren stalks were infected mostly in the ear, below the ear, and on the neck. Smut on tassels did not reduce yields.

Immer and Christensen (6), working at Minnesota, found losses ranging from 7 to 94%, depending on the size and location of the smut galls The sizes of smut galls were classified as small, under 2 inches in diameter; medium, 2 to 4 inches; large, over 4 inches. Like Garber and Hoover, they found that infections above the ear were more deleterious to yields than the same size galls below the ear. Total above-ear infections reduced yields 51% while below-ear infections reduced the yield 35%. In a later paper the same authors (7) reported results which led to the conclusion that there is a direct proportion of loss in yield and size of smut galls and that galls above the ear reduced yields more than the same size galls below the ear. The reduction in yield was estimated to be 50% for large galls, 25% for medium, and 10% for small galls. Selfed lines reacted similarly to smut in different seasons.

Johnson and Christensen (8) made an exhaustive statistical study of yields and smut infections. The variables used in these studies were size of galls, location of galls, number of galls, and location and size of multiple galls. Yields were based on dry weights of corn without shelling. The various classes of smutted plants were compared with adjacent smut-free plants and statistically analyzed by Student's method. The size classes used were similar to those in other reports (7, 8). Small galls reduced yields 2% when below the ear, 11.6% when above the ear, 21% when located on the ear, and 7.2% when located on the tassel None of these differences were statistically significant. Medium-sized galls reduced yields 16.5% when below the ear, 33.0% when above the ear, 22.0% when on the ear, and 88.4% when on the tassel. All these differences were statistically significant. Large galls reduced yields 41.7% when below the ear, 86.7% when above the ear, 83.4% when on the ear, and 100% when on the tassel. All these differences were significant. The effect of the number of galls of different sizes was studied. Two small galls reduced yield approximately as much as a medium-sized gall in the same location. Losses from medium-sized and small galls were directly proportional to their number. Losses from two large galls usually were nearly 100%. In addition these authors found that grain from smutted plants had poorer luster and were more affected by ear rots.

Jorgensen (9), working in Ohio, classified the plants by location of infection but did not report any size differences of smut galls. In selfed lines, infections below the ear gave a decrease of 42%, while a 16% decrease was observed from infections above the ear in selfed lines. Ear infections reduced yield 55%. In F_1 crosses below-ear infections reduced yields 24%, above-ear infections 38%, and ear infections 74%. Only a few comparisons were made on tassel infections and the results were inconclusive. In the selfed lines, the average reduction due to all smut infections was 39% and in the F_1 crosses 50%.

MATERIALS AND METHODS

This study was made in a commercial field of King Philip Hybrid grown about 14 miles west of Stockton on Roberts Island. The land is peat soil from reclaimed tule marshes in the delta of the San Joaquin River.

In order to measure the prevalence of the disease, five counts of 500 plants each were made at random in the field. The sizes and locations of galls on each infected plant were recorded. In each sample the plants were counted consecutively in a single row. The results are summarized in Tables 1, 2, and 3.

Since most of the infections were below-ear, on-ear, and multiple galls only these classes were harvested for yield measurements. No attempt was made to measure losses due to smut on the base, above the ear, or on the tassel because their prevalence was of minor significance.

The ears harvested for yield comparisons were taken in the same field that the counts were made. Three general groups were harvested, with galls below the ear, on the ear, and multiple galls. The sizes of the smut galls were classed the same as by the Minnesota workers (6, 7, 8), small galls being those less than 2 inches, medium galls from 2 to 4 inches, and large galls being over 4 inches in diameter. Ears were harvested from smutted and adjacent nonsmutted plants. Each pair was given the same number. The ears were shelled and the yields were expressed as grams of shelled corn. The results were analyzed by Student's method.

RESULTS

The results of the plant counts are presented in Tables 1, 2, and 3. In Table 1 the counts of single galls are shown, while in Tables 2 and 3 the counts of multiple galls are presented, classified by size in Table 2 and by location in Table 3. There were 435 smutted plants in a total of 2,500 plants, or 17.4%. There were 341 plants with single-gall infections, or 13.64%, and 94 plants with multiple-gall infections, or 3.76%.

In Table 4 are presented the results of the yields from smutted and nonsmutted plants. The number of comparisons in each case is not large, but most of the differences are statistically significant. Odds were calculated from Miles (10) tables which were derived from Student's tables. In cases where N was more than 20 the method outlined by Student (11) was used.

BARRENNESS CAUSED BY SMUT

Large galls caused 35% barren stalks when infection was below the ear and 52% when on the ear. Two or more large galls caused 100% barren stalks. A large and medium gall caused 60% barren stalks. No barren plants were found with medium galls below the ear

TABLE 1.—*Counts of single-gall infections of corn smut on Roberts Island, Nov. 20, 1935, each count representing a sample of 500 plants taken consecutively in a single row.*

Count No.	Base			Below ear			Ear			Above ear			Tas-sel			Leaf	Total in size class			Grand total
	S*	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	S	M	L	
1	1	—	—	21	16	3	2	16	9	1	—	—	1	—	1	1	27	32	13	72
2	—	1	—	14	6	1	2	5	9	—	2	1	—	—	1	—	16	14	12	42
3	2	2	—	19	13	1	10	12	17	—	—	—	—	—	—	2	33	27	18	78
4	—	—	—	29	19	3	5	13	9	1	—	—	—	2	—	—	35	34	12	81
5	—	1	1	21	13	3	9	8	8	1	1	—	—	—	—	2	33	23	12	68
Total in each class	3	4	1	104	67	11	28	54	52	3	3	1	1	2	2	5	144	130	67	341
Total at each location	8			182			134			7			5			5	341			341

*S = Small, diameter less than 2 inches; M = Medium, diameter 2 to 4 inches; and L = Large, diameter over 4 inches.

TABLE 2.—*Counts of multiple-gall infections of corn smut on Roberts Island, Nov. 20, 1935, each count representing a sample of 500 plants taken consecutively in a single row and classified by size.**

Count No.	SS	SSS+	SM	SM+	SL	MM	MM+	ML	ML+	LL	LL+	Total
1	2	4	8	—	1	4	—	4	—	1	2	26
2	2	—	3	—	—	—	3	1	2	2	3	16
3	—	1	1	1	1	6	1	1	2	2	-	16
4	1	—	8	1	3	8	1	1	1	3	2	29
5	—	1	2	—	1	—	—	—	3	-	—	7
Total in each class	5	6	22	2	6	18	5	7	8	8	7	94

*S = Small, diameter less than 2 inches; M = Medium, diameter 2 to 4 inches; L = Large, diameter over 4 inches; SS = 2 small galls; SSS + = 3 or more small galls; SM = 1 medium and 1 small gall; and SM + = 1 medium and 1 or more small galls.

TABLE 3.—*Counts of multiple-gall infections of corn smut on Roberts Island, Nov. 20, 1935, each count representing a sample of 500 plants taken consecutively in a single row and classified by location.**

Count No.	BE	BE-E	BE-AE	BE-E-AE	E	Total
1	14	8	2	—	2	26
2	6	9	—	—	1	16
3	7	5	—	—	4	16
4	15	12	1	1	—	29
5	4	3	—	—	—	7
Total	46	37	3	1	7	94

*BE = Below ear; E = ear; and AE = Above ear.

and only 4% when on the ear. Two multiple galls of medium size did not result in barren stalks. Barren stalks with small galls were not found except where there were three or more. Thus, there is a direct relation of barrenness and size of smut galls. This is in agreement with results obtained by other workers (8).

TABLE 4.—*Effect of size and location of smut galls on yield of shelled grain in King Philip Hybrid, 1935.*

Size of gall*	Number of comparisons	Average loss on smutted plants in grams of shelled grain per plant	Standard error	Percentage reduction	Odds	Number of comparisons in which smutted plants outyielded nonsmutted	Number of smutted plants barren	Percentage of smutted plants barren
				Below Ear				
S	37	12.06	13.11	6.46	4.3:1	16	0	0
M	45	14.37	10.39	7.34	10.3:1	19	0	0
L	17	78.52	22.67	40.53	609:1	3	6	35
				On Ear				
S	18	41.92	12.83	23.38	401:1	2	0	0
M	25	74.62	14.33	40.59	>20000:1	3	1	4
L	23	139.43	14.75	81.67	>20000:1	1	12	52
				Multiple Galls Below Ear				
SS	9	26.20	23.26	12.26	6.0:1	3	0	0
SSS+	4	90.65	33.89	44.28	25.4:1	0	1	25
MS	7	67.13	36.27	37.52	16.6:1	2	0	0
MM or MSS	7	93.43	24.27	48.13	235:1	0	0	0
ML or LSS	5	130.64	42.98	73.19	51:1	0	3	60
LL	2	212.05	3.62	100.00	363:1	0	2	100
				Below Ear and On Ear, All Sizes				
	16	108.66	22.99	57.68	9999:1	2	5	31
				Below Ear and Above Ear, All Sizes				
	5	124.18	27.76	80.75	180:1	0	2	40
				All Locations				
SS	10	37.40	23.63	18.15	12.4:1	3	1	10
SSS+	6	79.33	17.91	41.71	292:1	0	1	17
MS	13	58.92	22.13	33.98	96:1	3	3	23
MM or MSS	4	93.67	19.42	43.04	117:1	0	0	0
MMM+	10	120.02	25.54	63.94	1666:1	1	1	10
ML or LSS	8	135.06	26.52	76.87	1428:1	0	3	37
LL+	4	155.35	25.76	100.00	218:1	0	4	100

*See Tables 1 and 2 for meaning of symbols.

EFFECT OF LOCATION OF SMUT GALLS

A number of investigators have found that in selfed lines the incidence of attack may be limited to certain areas of the plant (1, 4, 5, 6, 7, 8). From this study it seems that King Philip Hybrid is not susceptible to great smut attack at the base, above the ear, and on the tassel. The five cases of smut on the tassel recorded in Table 3 were all on suckers. From these data it is not possible to compare losses from above-ear and below-ear infections. There is, however, conclusive evidence, presented in Table 5, that smut on the ear causes more loss than similar-sized galls below the ear. The differences are hardly significant for small galls but are highly significant for medium and large ones.

TABLE 5.—*Effect of location of smut galls on yields.*

Size of gall	Loss in grams from galls		Difference in grams	Odds
	On ear	Below ear		
Small	41.92±12.83*	12.06±13.11	29.86±18.35	18.5:1
Medium	74.62±14.33	14.37±10.39	62.25±17.70	4695:1
Large	139.43±14.75	78.52±22.67	60.91±27.05	81.7:1

*Standard error used in all cases.

EFFECT OF SIZE OF SMUT GALLS IN REDUCING YIELDS

From the data presented in Table 4 it is possible to calculate the average losses due to galls of different sizes When galls are all the same size in multiple-gall infections the reduction in yield can be calculated directly by division. When multiple galls are of different sizes the calculations must be made indirectly Thus, two small galls below the ear reduce the yield 26.20 grams, or 13.10 grams each, and two medium galls 93.43 grams, or 46.72 grams each. A medium and a small gall should reduce yield 59.82 grams. Actually, the reduction for this combination was 67.13 grams, a difference of 7.31 grams. Thus, the reduction in yield due to each gall size can be calculated by interpolation. For example:

For small galls in an MS combination $13.10+(7.31\times.219)=14.70$.

For medium galls in an MS combination $46.72+(7.31\times.781)=52.43$.

Similarly, medium galls reduce yields 46.72 grams and large galls 92.28 grams. But 92.28 plus 46.72 is 139.00, while the actual loss in ML combinations is 130.64 grams, a difference of 8.36.

Then for medium galls in an ML combination $46.72-(8.36\times.276)=44.41$ and for large galls in an ML combination $92.28-(8.36\times.724)=86.23$.

The reductions in yields due to different sizes of galls in various combinations are presented in Table 6. Losses expressed in percentages are based on the average yields of nonsmutted plants used as checks. The average yield of 133 plants was 193.06 grams.

Thus, a gall on the ear reduces yield about twice as much as a similar-sized gall below the ear. The reduction in yield for small- and medium-sized galls is proportional to the number. Medium-sized galls

TABLE 6.—*Effect of size of smut galls in reducing grain yields in King Philip Hybrid corn.*

	Small galls		Medium galls		Large galls	
	Combination*	Loss in grams	Combination*	Loss in grams	Combination*	Loss in grams
Below Ear						
	S	12.06	M	14.37	L	78.52
	SS	13.10	MM	46.72	LL	106.03
	MS	14.70	MS	52.43		
			ML	44.41	ML	89.97
Average		13.29		39.48		91.51
Percentage reduction		6.88		19.36		47.40
On Ear						
	S	41.92	M	74.62	L	139.43
Percentage reduction		23.38		40.59		81.67

*See Tables 1 and 2 for meaning of symbols.

reduce yields about two to three times as much as small galls and large galls reduce yields about twice as much as medium ones. These results are essentially similar to those obtained by Johnson and Christensen (8) in which small galls below the ear reduced yields 11.6%, medium galls 16.5%, and large galls 41.7%. On the ear small galls reduced yields 21%, medium galls 22%, and large galls 87.4%.

ESTIMATION OF LOSSES IN THE FIELD

From the data in Table 4 it is now possible to estimate the losses sustained in the field as shown by the sample counts. These estimations are presented in Table 7.

The estimated values of losses from smut galls of different sizes and locations are taken from Table 4. Losses due to below-ear infections were taken from the calculations made in Table 6. Since there are no data available on losses due to above-ear infections, the same values as below-ear infections were used. This is probably not justifiable according to results obtained by workers at Minnesota (6, 7, 8) and Ohio (9), but the number of affected plants is so small that a change in the value would not materially affect the total. The same holds true for smutted tassels. In cases of multiple galls the estimates are made as closely as the data in Table 4 will permit. Multiple galls at all locations are used as a basis of estimation. Since no measurements were made of some of the multiple combinations, the nearest measurement is used, thus for SM+, SM is used and for ML+, ML is used. These estimates give a total loss due to smut at 6.0% from a field with 17.4% smutted plants. About two-thirds of the loss is from single galls. The greatest loss is from smut on the ear which amounts to 2.8%.

CONCLUSIONS

The data presented in this report, although not as extensive as other reports of a similar character (2, 3, 6, 7, 8, 9), definitely show

TABLE 7.—*Estimation of losses in the field due to smut from a random sample of 2,500 plants.*

Location of gall	Size of gall*	Number of plants	Estimated loss per plant %	Loss in total yield %	Percentage reduction
Base	S	3	7	0.0084	
	M	4	19	0.0304	0.0576
	L	1	47	0.0188	
Below ear	S	104	7	0.2912	
	M	67	19	0.5092	1.0072
	L	11	47	0.2068	
Ear	S	28	23	0.2576	
	M	54	41	0.8856	2.8488
	L	52	82	1.7056	
Above ear	S	3	7	0.0084	
	M	3	19	0.0228	0.0500
	L	1	47	0.0188	
Tassel	S	1	7	0.0028	
	M	2	19	0.0152	0.0556
	L	2	47	0.0376	
Leaf	S	5	7	0.0014	0.0014
Total single galls		341			4.0206
Multiple galls, all locations	SS	5	18	0.0360	
	SSS+	6	42	0.1008	
	SM	22	34	0.2992	
	SM+	2	34	0.0272	
	SL	6	43	0.1032	
	MM	18	43	0.3096	
	MM+	5	43	0.0860	
	ML	7	76	0.2128	
	ML+	8	76	0.2432	
	LL	8	99	0.3168	
	LL+	7	100	0.2800	
Total multiple galls		94			2.0148
Total					6.0354

*See Tables 1 and 2 for meaning of symbols.

that corn smut causes considerable reductions in grain yields in California. In a corn breeding program, of which this is a part, we are attempting to reduce losses by breeding methods. This task is not altogether hopeless in spite of the marked variance of pathogenicity of the forms of the smut organism, for a number of workers have noted selfed lines which are constant in their reaction. Christensen and Johnson (1) and Immer and Christensen (7) have shown that selfed lines react similarly when subjected to epidemics of smut obtained from several sources.

SUMMARY

Grain from 220 pairs of smutted and adjacent nonsmutted plants was weighed. Analyses of differences were made by Student's method.

Losses from smut infection on the ear and below the ear were calculated for small, medium, and large galls. Losses due to multiple galls of a number of different combinations were calculated. Losses due to smut below the ear are estimated to be 7% for small, 19% for medium, and 47% for large galls. Ear infections gave greater losses, 23% for small, 41% for medium, and 82% for large galls.

The percentage of barren stalks increased with the amount of smut. In stalks with large galls on the ear, 52% were barren, while 35% were barren when large galls occurred below the ear. Single small galls produced no barren stalks, neither did medium galls below the ear, but medium galls on the ear caused 4% barrenness. Multiple small and medium galls caused an increase in the percentage of barren stalks. Two or more large galls produced 100% barren stalks.

The estimated loss in yield in the field having 17.4% smutted plants was 6.0%.

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CAN DIFFERENT DEGREES OF BUNT RESISTANCE BE RECOGNIZED IN F_2 PLANTS?[1]

A. M. SCHLEHUBER[2]

IN studies on the genetics of smut resistance some controversy exists as to the most logical method of classification of the smutted plants. It is recognized here, as in other genetic studies, that the plant should be considered as the unit. However, the expression of unity apparently is not well understood. Briggs (1)[3] in 1926 criticized the methods of Gaines (2) in 1923 in which the plants were grouped in three different classes, *viz.*, bunt-free, all bunted, and partly bunted. It was thought by Briggs that this method merely gave a satisfactory quantitative measure of resistance but did not maintain the plant as a unit. Briggs' method consists of dividing the plants into two classes, bunt-free and bunted. Gaines counted the good and bunted heads on the partly bunted plants, giving credit for the wheat produced in computing percentages of bunt.

Smith (4) divided the plants into five bunt-percentage groups for greater ease in counting than was possible by Gaines' method, although the end result was practically the same. He presented data which seem to indicate that genetic differences may be concealed when plants showing various degrees of smutting are placed in one group. One of Smith's tables is reproduced here as Table 1

It can be noted in Table 1 that the number of bunt-free plants in the two varieties is approximately the same, whereas the distribution is very different. In this example, if the percentage of bunt is based on two groups, bunt-free and bunted, the percentage of bunt in the two varieties is approximately the same, 87% for Hybrid 128 and 86% for Martin; whereas it is approximately double if based on the degree of smutting, 83% for Hybrid 128 and 39% for Martin. Smith states, "It would be conceded that these differences between varieties are due to differences in reaction." Naturally, similar differences would be expected between hybrids.

MATERIALS AND METHODS

Plants which showed various degrees of smutting were selected from an Oro x Hybrid 128 F_2 population grown in the cereal nursery at the State College of Washington, Pullman, Wash., in 1932. The F_2 seed had been inoculated with a composite mixture of physiologic bunt forms. The plants were grouped according to Smith's classification as smut-free and 20, 50, 80, or 100% smut. All the seed from the first four groups was saved and their identity maintained. Bunt collected

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[3]Reference by number is to "Literature Cited," p. 270.

TABLE 1.—*Distribution of plants among the five bunt-percentage groups and percentage of bunt in each row of duplicate rows of Hybrid 128 and Martin wheat inoculated with physiologic form T-2 and grown in 1930. (After Smith, 4, page 93.)*

Row No.	Number of plants in bunt-percentage group indicated					Total No. of plants	Percentag of bunt in row
	0	20	50	80	100		
			Hybrid 128				
1	5	0	1	2	20	28	79
291	3	1	0	3	26	33	87
			Martin				
5	3	7	5	6	0	21	41
299	4	12	8	4	1	29	37*

*Percentage of bunt in row 299 = $\frac{(20x12)+(50x8)+(80x4)+(100x1)}{29}$ = 37.

Briggs' method: $\frac{12+8+4+1}{29}$ = 86% smut.

from the totally bunted plants was used to inoculate the F_3 seed. The seed from each F_2 plant was planted in a rod row of 75 seeds each. The rows of each group were distributed uniformly throughout the field. Sufficient check rows of Hybrid 128 were included to test the viability of the inoculum.

At harvest time the plants from each row were again classified into the smut groups and the percentages of smut computed.

On account of the severe winter in 1933 many of the plants winter-killed and for this reason it was felt that the results obtained that year were rather inconclusive. Consequently, a similar study was carried on the following year. This time a White Odessa (Wash. 2308) x Turkey-Florence (Wash. 2471) F_2 population was used. The methods used were the same as those for the preceding year with the exception that, in addition to the check rows of Hybrid 128, check rows of White Odessa and Turkey-Florence were planted.

RESULTS

The average percentage of smut of the two F_3 families is shown in Table 2.

TABLE 2.—*Smut reaction of F_2 and F_3 families of two winter wheat crosses when inoculated with a composite mixture of physiologic forms of bunt.*

Cross	F_2 smut classes											
	Smut-free			20%			50%			80%		
	Av. % smut in F_3	Range	No. rows	Av. % smut in F_3	Range	No. rows	Av. % smut in F_3	Range	No. rows	Av. % smut in F_3	Range	No. rows
Oro x Hyb. 128	8	0–70	66	20	0–100	22	30	9–82	23	26	0–86	18
Wh. Od. x T-F	47	11–89	39	59	12–94	41	69	45–96	40	75	46–98	30

As indicated in Table 2 there was an average of 8% of smut in the F_3 rows grown from seed of F_2 smut-free plants of Oro x Hybrid 128. The range in percentage of smut indicates that a number of the F_2 plants escaped infection. In some cases the presence of smut in the F_3 families may have been due to the action of dominant resistant genes in the F_2. The amount of smut produced in the F_3 from the 80% smutted F_2 plants is low.

The differential effect of winterkilling on smut-susceptible and non-susceptible varieties is clearly demonstrated by the results of a smut and winterhardiness experiment carried on the same year by Holton and Schlehuber (3). They found that the percentage stand varied considerably but was lowest in Hybrid 128, the most susceptible variety, and highest in Jenkin-Ridit (Wash. 2807), the most resistant variety used in the experiment. They also found that the average percentage of smut for two series in Hybrid 128 was 80 for those rows grown from seed that was inoculated with only a trace of smut and 65 for those which received a heavy inoculation. Considering the fact that the fall stand was the same in both cases this would seem to indicate that the most smut-susceptible plants were the most easily winterkilled. This fact may possibly explain why the amount of smut is very much reduced in the 80% smutted F_3 families in Oro x Hybrid 128.

The White Odessa x Turkey-Florence F_3 was studied and analyzed in somewhat greater detail than the other cross. Sixteen rows of Turkey-Florence had an average of 30 ± 3.69% smut and a range from 22 to 41%. Sixteen rows of White Odessa had an average of 86 ± 3.04% smut and a range of 77 to 92%. In both cases the deviations do not exceed three times the probable error.

One hundred and fifty F_3 rows were planted which represented an F_2 grouping of 39 smut-free, 41 of 20% smut, 40 of 50% smut, and 30 of 80% smut. The reaction of these F_3 lines is represented in Fig. 1.

Five classes of smut ranges are represented in Fig. 1, *viz.*, class I, 0 to 21% smut, exceeds the resistance of Turkey-Florence; class II, 22 to 41% smut, the range of Turkey-Florence; class III, 42 to 76% smut, the range between the two parents; class IV, 77 to 92% smut, the range of White Odessa; and class V, 93 to 100% smut, exceeds the susceptibility of White Odessa.

Fig. 1 shows that only F_3 families descending from smut-free and 20% smutted F_2 plants are represented in the first two classes, and that there are comparatively more of the smut-free than of the 20% lines. This condition is reversed in the classes representing the higher smut percentages until in class V there are no F_3 families from smut-free F_2 plants. The 20% smut families are represented in every class with a distribution approximating a normal curve, the percentages in classes I to V being: 2.4, 17.0, 65.8, 12.1, and 2.4, respectively.

Another significant comparison is that between the lines descending from the 50 and the 80% smutted F_2 plants. No families from these groups appear in classes I and II. In class III there are 70% of all 50% smutted plants tested and only 46.6% of the 80% group. In class IV, however, there are only 27.5% of the 50% group and 43.3%

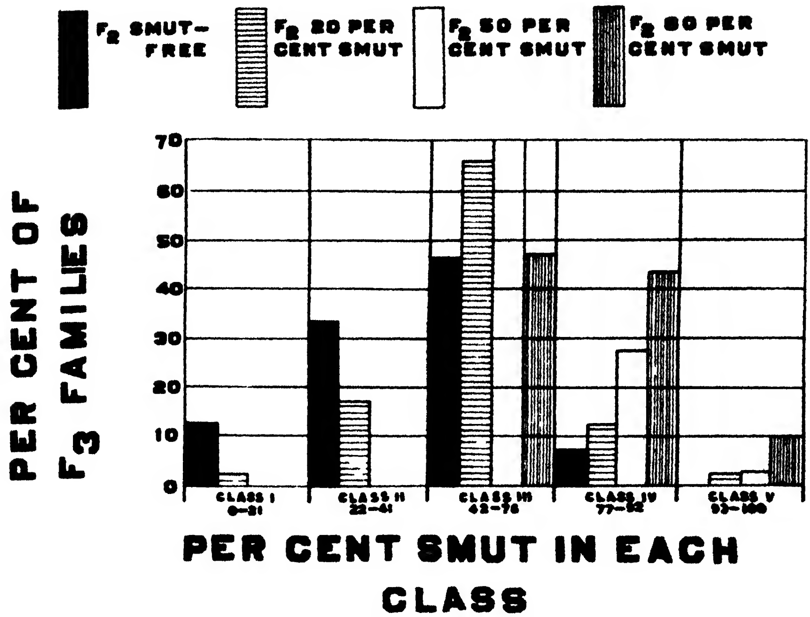

FIG. 1.—Reaction of White Odessa × Turkey-Florence F_3 to a mixture of smuts when selected from smut-free, 20%, 50%, and 80% F_2 plants. The range of Turkey-Florence was 22 to 41% smut and that of White Odessa 77 to 92%. There are three classes of F_3 families different from the parents, one more resistant, one intermediate, and one more susceptible.

of the 80% group. In class V there are twice as many F_3 families from the 80% group as from all the other groups added together.

The segregation of F_3 families from the various F_2 smut groups in class IV apparently presents differences in genetic constitution of the different groups. Here, the percentage of F_3 families descending from each group is as follows: Smut-free group, 7.6; 20% group, 12.1; 50% group, 27.5; and 80% group, 43.3.

The practical application of these facts in a breeding program for smut resistance can be readily illustrated. For instance, when smut-free and 20% smutted F_2 plants are selected from a cross of this type, it is possible to obtain families that are more smut resistant than either parent. If 50% and 80% F_2 plants are selected, it is impossible to obtain families that are even as resistant as the resistant parent. Smut-free F_2 plants produced five times as many resistant F_3 families as the F_2 plants that were 20% smutted.

CONCLUSIONS

Data are presented which show definitely that different degrees of bunt resistance can be recognized in F_2 plants. The data are evaluated from the standpoint of a practical application in a program of breeding for bunt resistance.

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RESISTANCE OF SORGHUM TO STEM BORERS[1]

Tien Sih Hsu[2]

STEM borers are notorious insect pests of common occurrence in North China. There are several species infesting sorghum of which the most important are *Pyrausta nubilalis* and *Diatraea diatraea*. This paper records results of studies of the extent of infestation by stem borers in sorghum in Peiping, China.

REVIEW OF LITERATURE

Marston (5, 6, 8)[3] found that a South American strain of flint corn, Maize Amargo, was highly resistant to the corn borer, ***Pyrausta nubilalis*** Huebn, since the moths did not lay their eggs on it. It was crossed with various strains of dent corn. The F_1 was quite susceptible, but the F_2 much less so, showing that segregation had occurred. The results indicated a monohybrid segregation.

Sweet corn growers in Michigan found it difficult to market corn due to the fact that practically all ears were infested by the corn borer. However, certain F_3 and F_4 inbred lines from crosses of Golden Bantam with Maize Amargo showed considerable reduction in infestation (7).

Shen and Shen (13) found at Nanking that over a period of 5 years the rice strain 1-3-86 was consistently damaged the least by ***Schoenobius incertillus*** Wlk, and ***Chilo simplex*** Bult. One variety, named Ningpo Sen, which was very resistant to the borers, had the ability to produce about 70% more tillers than other varieties of rice.

Sorghum varieties differ very sharply in their ability to resist the chinch bug attack. The exact basis of resistance and susceptibility is unknown, but the structure of the stem, amount of lignified tissue, and arrangement of fibrovascular bundles may be considered as factors of some importance (10, 12).

Painter, Salmon, and Parker (11) supplied evidence to indicate that some varieties of winter wheat, such as Fulhard and Kawvale, possess a high degree of resistance to the Hessian fly, ***Phytophyga destructor*** Say, that factors for resistance are inherited, and that fly resistance may be combined with other desirable characters. Considerable evidence was given also for the presence of biological strains of the Hessian fly.

An account of aphis immunity of teosinte-corn hybrids was given by Gernert (3). He stated that teosinte was practically immune from attack by corn aphis, *Aphis maidis*, as determined from a trial conducted for 2 years. A cross was made between teosinte and yellow dent corn, and the F_1 progenies were found to be as resistant as the teosinte. It was believed that susceptibility in corn might be correlated with the production of sweet juice.

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[2]Agronomist and Chief of the Division of Agronomy, Kwangsi Agricultural Experiment Station, Linchow, Kwangsi, China. The data were taken when the writer was in charge of sorghum breeding at the Crop Improvement Station, Yenching University, Peiping, China. The writer wishes to express his appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, under whose direction the analysis of the data was made and the manuscript was prepared.

[3]Figures in parenthesis refer to "Literature Cited," p. 278.

Chopra (1) found that the indigenous varieties of cocksfoot grass suffered far more severely from the cocksfoot moth, *Glyphipteryx fischeriella* Zell., than those from foreign countries because of the coloration of panicles at the flowering stage. It was noticed at the flowering stage that the indigenous varieties had a steel blue tinge upon the panicles, while the foreign strains were mostly green to pale yellow. The coloration difference has, therefore, some influence in guiding the moth in its choice of plants upon which eggs are laid.

Results obtained by Isely (4) indicate that the boll weevil had a marked preference for cotton plants with green foliage over those with red foliage.

The pH value is important in determining resistance of apple varieties to the woolly aphis. A study made by Monzen (9) shows that the apple variety susceptible to woolly aphis has a pH value of 5.0, whereas in the resistant variety the pH value is 4.4 only. There is another factor for the resistance to woolly aphis, i.e., the amount of sclerenchyma around the circumference of the stem. Staniland (15) classified apple stocks into four groups as follows: The very susceptible group containing 61 to 65% sclerenchyma, the susceptible group containing 66 to 70% sclerenchyma, the resistant group containing 71 to 75% sclerenchyma, and the immune group containing 76 to 80% sclerenchyma.

MATERIALS AND METHODS

Three groups of strains and varieties of sorghum were tested in 1933. Group I consisted of 981 strains with 2 replications, group II of 16 strains with 5 replications, and group III of 76 strains and varieties with 10 replications. In all cases, single-row plats were used. The strains and varieties grown in these groups were obtained from various sorghum-producing regions in North China. In addition, 10 varieties were introduced from the United States.

The number of plants in a row and number of plants infested were determined in the field. The data thus secured were converted into percentage as a common basis for comparison.

For the 1934 planting, selections of strains and varieties that were apparently resistant and susceptible in 1933 were made for the purpose of determining whether resistance was inherited. The method of planting was much the same as that used for rod-row trials of small grains. There were 10 replications.

All strains and varieties which appeared resistant in 1933 were selected for further study. Single 8-foot-row plats were used, each being covered with a tent of cheesecloth 9 feet long and 1½ feet wide. When the crop averaged about 2 feet high, four moths were introduced into each of the tents. After about three weeks, notes on infestation were taken in each row and all infested plants were counted and removed. A second study of controlled infestation was made by placing two newly hatched larvae on each uninfested plant in each tent, the larvae being collected from sorghum seedlings planted in the field.

A wire cage was used for raising moths. A number of infested stalks were placed in the cage and moths were caught and introduced into the experimental tents as soon as they were available. Another method used to raise moths consisted of collecting pupae and large larvae from the infested stalks and dropping them into well-ventilated bottles.

A large cheesecloth tent about 23 feet long, 10 feet wide, and 12 feet high was used for investigations of the host selection of moths. Under this tent 13 apparently resistant strains and varieties were planted together with 5 susceptible ones as well as 6 varieties of sorgo. Eight plants were grown of each strain or variety.

The significance of differences between varieties in regard to the degree of infestation was tested by Fisher's (2) analysis of variance, and the extent of correlation between 1933 and 1934 infestation was studied by means of the correlation coefficient. The possible association between borer injury and plant character differences was studied by means of X^2 for independence.

EXPERIMENTAL RESULTS

BORER INJURY IN 1933

Among 981 strains of sorghum replicated twice, there were 23 with less than 4% infestation and 29 with more than 25%. Sixteen strains grown in another trial with five replications gave borer injury ranging from 3.4 to 16.5%.

Seventy-six strains and varieties were grown in a 10-row trial with results as follows:

	% Borer Injury					
	0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	more than 20	Total
Number strains and varieties	11	25	25	10	5	76

These figures show considerable variation in infestation by stem borers in sorghum. An analysis of variance (Table 1) was made to determine whether the differences were significant statistically. The value of F for a comparison of variation between varieties and error was 9.69 (dividing 321.20 by 33.14). According to Snedecor's (14) table, the highly significant value is about 1.08 for 75 degrees of freedom for the greater mean square and 684 degrees of freedom for the smaller mean square. Obviously, the variance for varietal infestation is of very high significance.

TABLE 1.—*Results of analysis of variance in the 10-row trial, 1933.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F
Varieties.......	75	24,089.77	321.20	9.69
Error.........	684	22,670.10	33.14	
Total	759	46,759.87		

BORER INJURY IN 1934

Selections of strains and varieties of sorghum that were classed as resistant and susceptible were made in 1933 for further test. They were planted in the field in 1934 together with six varieties of sorgo. Results of infestation are summarized as follows:

	% Borer Injury					
	0-4.9	5.0-9.9	10.0-14.9	15.0-19.9	more than 20	Total
Number strains and varieties........	7	7	8	2	1	25

An analysis of variance was made also to study the significance of differences in borer injury between various strains and varieties.

Either because of poor stand or because of missing rows, five varieties were excluded from the calculation. The results of the analysis of variance are presented in Table 2. When F equals 1.92, it is on the 1% point. Therefore, it is considered that the variance for varieties is much greater than the variance for error.

TABLE 2.—*Results of analysis of variance for the field test, 1934.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F
Varieties	19	4,900.08	257.90	6.56
Error	180	7,075.67	39.31	
Total	199	11,975.75	—	

The correlation between percentage of borer infestation in 1933 and 1934 was determined. Only 13 strains and varieties having the same number of replications and grown in both years were used for this study. A correlation coefficient of .72 was obtained for the extent of infestation between 1933 and 1934. According to Table VA (Fisher, 2), r is on the 1% point when its value equals .6835 and there are 11 degrees of freedom. Therefore, the correlation appears rather significant. Too much importance, however, must not be given to a single correlation coefficient where only 13 pairs of variables are available. The results obtained may indicate that there is a fairly high association between 1933 and 1934 so far as borer injury is concerned, and that the extent of infestation seems more or less consistent in a strain or variety. The strains and varieties grown in both years were used also in studying the interaction between years The results are given in Table 3.

TABLE 3.—*Analyses of variance for percentage of borer infestation 1933, 1934.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares
Varieties	12	14,437.10	1,203.09
Years	1	12.63	12.63
Varieties x years	12	3,362.10	280.18
Error	234	10,587.73	45.25
Total	259	28,399.56	—

The variance for "varieties" and the variance for "interaction of varieties with years" are both significantly greater than that for error, as shown by very high values of F. With 12 degrees of freedom for the larger mean square and 234 degrees of freedom for the smaller mean square, F is on the 1% point at a value of 2.28. The variance in "varieties" compared with error gave an F value of 26.59 and shows the existence of significant differences between strains and varieties in the infestation by stem borers, whereas the variance in "interaction of varieties with years" compared with error gave an F value of 6.19 and reveals the fact that the differences between these varieties in the extent of injury were not constant for the two years.

For the purpose of testing under controlled conditions the varieties that were found least infested in 1933, plantings were made separately

under cheesecloth tents and moths were introduced when the plants averaged about 2 feet in height. It was found that all were infested with the exception of three varieties, A93, A94, and A95, although there were wide differences in the extent of infestation. A few days later two newly hatched larvae were placed on each plant not previously infested. Notes on borer injury were taken at the end of July. The results indicate that without a single exception all varieties were infested both on leaves and stems.

In order to study the host selection of moths, all varieties and strains which were found to be slightly or heavily infested in 1933 were planted under a cheesecloth tent together with six varieties of sorgo. After the plants grew 2 to 5 feet in height, about 50 moths were liberated in the tent. The number of plants infested by stem borers was observed afterwards in each strain or variety. The detailed data are not presented here. Of six varieties of sorgo, four were infested by stem borers. Among 13 sorghum strains and varieties that were slightly infested in 1933, only three of them suffered from borer invasion. On the contrary, two out of five varieties which were heavily injured in 1933 carried no infestation. In other words, on the average, sorgos suffered most from borers, next came the strains and varieties which were heavily infested in 1933 and last the varieties which appeared resistant in 1933. There are, however, several exceptions to this rule. These results tend to show that probably the moths had a greater tendency to lay eggs upon plants of the sorgo and "susceptible" varieties.

ASSOCIATION BETWEEN INFESTATION AND PLANT CHARACTERS

Studies were made in 1933 of the relation between the percentage of borer infestation and color of grains, height of plant, and stiffness of stalks. Table 4 gives a contingency surface for the relation of percentage of infestation and color of grains in the 10-row trial of 1933. A study of the results given in this table leads to the conclusion that varieties with white grains suffered least from the pest and that varieties with pink grains were less infested than those with yellow or red grains.

TABLE 4.—*The frequency distribution of plats according to borer injury and color of grains in the 10-row trial, 1933.*

Color of grains	Percentage of borer injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	More than 20	Total
White	87	16	5	1	1	110
Pink	19	13	13	3	2	50
Yellow	32	36	75	23	44	210
Red	47	79	128	47	59	360
Total	185	144	221	74	106	730

Table 5 gives similar results for borer injury and height of plants. The shorter varieties appear to have less infestation than the varieties of medium height.

TABLE 5.—*The frequency distribution of plats according to borer injury and height of plants in the 10-row trial, 1933.*

Height of plants	Percentage of borer injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	More than 20	Total
Tall	68	51	74	10	7	210
Medium tall	29	32	68	29	42	200
Medium	21	40	71	34	54	220
Medium short	24	4	2	0	0	30
Short	32	11	3	1	3	50
Dwarf	11	6	3	0	0	20
Total	185	144	221	74	106	730

X^2 for independence was calculated to determine the possible association between borer injury and plant characters. In 1933 the results of the 10-row trial were used with the exception of three varieties which showed mixture in one character or another. Table 6 presents the results of calculation.

TABLE 6.—*The X^2 for independence between borer injury and plant characters, 1933.*

Characters studied	X^2	D/F	P
Borer injury and color of grains	230.0111	12	Less than .01
Borer injury and height of plants	205.2667	20	Less than .01
Borer injury and stiffness of stalks	4.4222	4	0.36

From Table 6 it is learned that borer injury is highly associated with color of grains and height of plants. There appears to be no association between stiffness of stalks and borer injury as the value of P obtained is much greater than .05.

Studies were also made in 1934 to determine the extent of association, if any, between borer injury and color of grains, height of plants, and stiffness of stalks. The data for stiffness of stalks were classified into two categories only, stiff and weak. As in 1933 there were five classes for extent of borer infestation. A contingency surface for infestation and stiffness of stalks is given in Table 7. No relation is obvious from a study of the table, and if apparent association is obtained, it may result from the small number of plats classified in the weak class.

TABLE 7.—*The frequency distribution of plats according to borer injury and stiffness of stalks, 1934.*

Stiffness of stalks	Percentage of borer injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	More than 20	Total
Stiff	50	26	26	7	14	123
Weak	2	2	10	7	9	30
Total	52	28	36	14	23	153

X^2 for independence was computed also with the data of 1934. Sorgos and three other strains were not included in the study because of lack of information as to plant characters. The results, which are given in Table 8, agree fairly well with those of 1933, except that stiffness of stalks showed no relation with borer injury in the preceding year and had a striking association in 1934.

TABLE 8.—*The X^2 for independence between borer injury and plant characters, 1934.*

Characters studied	X^2	D/F	P
Borer injury and color of grains.....	64.4466	12	Less than .01
Borer injury and height of plants.....	95.7911	20	Less than .01
Borer injury and stiffness of stalks...	26.5669	4	Less than .01

DISCUSSION

From the two years' experimental results it is doubtful if true resistance to stem borer is available in the sorghum varieties tested. Those with low injury probably escaped for various reasons such as differences in height of plant. The few moths introduced into each of the small tents with perhaps no eggs laid on seedlings may account for the fact that A93, A94, and A95 were free from infestation. This can be confirmed by results of the field trial showing that these three varieties were not completely free from borer injury, and also by the results of placing larvae on plants of all varieties in which case every strain or variety tested was severely injured.

Sorgos were heavily infested under controlled conditions, yet suffered little in the field test. This is probably because the dimensions of the tent were rather small as compared with a field, thus making probable the infestation of all varieties under the tent.

It was noticed from field tests that the extent of infestation by stem borers in sorghum varies with varieties. The host selection of moths may be considered as one of the causes for this phenomenon as shown by results obtained under controlled conditions.

The significant association between infestation and height of plants may be explained by the assumption that tall plants present more space to the borer's attack than the short and dwarf plants.

It seems peculiar that color of grains may have some relation with borer injury. It is hardly conceivable that color of grains itself should play a part in this regard. Possibly some other characters associated with white grains may be important factors for borer resistance. The exact explanation must await further study and for this purpose physiological factors, such as the amount and sweetness of plant juice, the pH value of cell sap, or morphological factors, such as the amount and distribution of sclerenchyma, or both, should be investigated.

SUMMARY

1. Grain sorghum is attacked by several species of stem borers, such as *Pyrausta nubilalis*, *Diatraea diatraea*, etc.

2. Data were obtained from the study of infestation in 1,073 strains

and varieties in 1933, indicating that the extent of infestation by stem borers varied with varieties.

3. Further data obtained in 1934 under both field and controlled conditions gave further indication of differences in varietal infestation.

4. Under controlled conditions sorgos as a group were more susceptible to the insect than the nonsaccharine varieties.

5. Host selection of the "laying" moths is a possible cause for the varying degrees of infestation in different varieties of sorghum.

6. The degree of infestation by borers is probably a heritable character as the correlation between 1933 and 1934 infestation was significantly high.

7. Studied by means of X^2 for independence, borer infestation was found to be consistently associated with color of grains and height of plants.

8. White grain varieties showed less infestation by borers than varieties with other grain colors. The reason for this relation is unknown.

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INHERITANCE OF RESISTANCE TO ROOT ROT IN TOBACCO CAUSED BY *THIELAVIA BASICOLA*[1]

T. C. McIlvaine and R. J. Garber[2]

During the past several years the West Virginia Agricultural Experiment Station, in cooperation with the Division of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, has had under way a project to produce by hybridization and selection a strain of Burley tobacco resistant to root rot caused by *Thielavia basicola*. Incidental to this investigation certain data pertaining to inheritance of disease resistance was obtained. The purpose of this paper is to present these data, together with a brief discussion of them.

Studies by Johnson and Hartman (1)[3] and by Johnson (2,3) have shown the importance of various environmental factors in the development of root rot in tobacco as well as the feasibility of breeding tobacco resistant to this disease.

MATERIALS AND METHODS

The parent resistant to root rot used in the present investigation and designated by the number 10 Ba, was derived from seed of hybrid origin obtained from Dr. James Johnson of the Wisconsin Agricultural Experiment Station. The seed obtained from Dr. Johnson was borne on F_4 plants descended from a cross between pure lines of a drooping leaf, resistant Burley and Judy's Pride Standup Burley. The individual plant used as the resistant parent of the crosses reported below was in the F_{12} generation obtained through successive hand pollinations and was of the standup Burley type. The susceptible Burley parent used was Kelly, an individual plant of a variety capable of yielding high-quality tobacco. The progenies resulting from crossing, backcrossing, and subsequent selfing the resistant and susceptible parents were grown in a seedbed known to be free from *Thielavia basicola* and set out in a heavily limed field known to contain this organism from previous crops of tobacco. Infested soil was obtained through the courtesy of Dr. W. D. Valleau of the Kentucky Agricultural Experiment Station. When the plants were set out their roots were dipped into a heavy soil suspension containing the root rot organism.

Each strain was grown in single-row plats replicated four times, with 25 plants per plat. The rows were 3 feet apart and the plants spaced 18 inches along the row. The field on which the plants were grown is located on first bottom along the Ohio River and is mapped as Huntington silt loam. The fertilizer used on the tobacco in 1933 and in 1934 consisted of 400 pounds per acre of a 4–10–6.

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[3]Figures in parentheses refer to "Literature Cited," p. 283.

The parents and the progenies which resulted from selfing the backcross to the susceptible Kelly parent were grown and studied during two years. As an indication of plant infection, height measurements were made. In 1934 measurements were made at three different times during the last half of the growth period.

DATA OBTAINED IN 1933

In Table 1 are shown the frequency distributions of average height in inches of the parents and hybrid progenies grown in 1933 at the Lakin Experiment Farm. Each hybrid strain was grown on quadruplicate plats systematically distributed. The average height for a particular strain is based on approximately 100 plants Similarly, each single unit in the frequency distribution for the parents represents approximately 100 plants on four systematically distributed plats. The plats occupied by the parental material were distributed throughout the nursery. The height measurements were made during three days, July 12, 14, and 17, before any of the plants had begun to bloom.

TABLE 1.—*Frequency distribution of average height in inches of progenies obtained by selfing backcrosses of the F_1 to the Kelly parent and of the parent plants grown in 1933 at Lakin, W. Va.*

Name	Mid-classes in inches																					
	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	32.5	Total
10 Ba parent....	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	2	—	2	1	—	7
Kelly parent....	—	1	—	—	4	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	7
(Kelly x 10 Ba) x Kelly, selfed..	1	1	2	6	5	7	7	12	15	13	10	14	11	10	9	5	2	2	4	—	1	137
(10 Ba x Kelly) x Kelly, selfed..	—	—	—	—	—	—	—	1	1	2	3	1	—	—	2	1	—	1	—	—	—	12

It is apparent from Table 1 that the average heights of the susceptible Kelly parent ranged significantly below those of 10 Ba, the resistant parent. The difference was striking and persisted throughout the whole of the growing period. The distribution of average heights of the 137 strains which resulted from backcrossing F_1 (Kelly x 10 Ba) to Kelly and then selfing was not dissimilar to that of average heights of the 12 strains which resulted from backcrossing the reciprocal F_1 to the same parent and then selfing the immediate descendants from this backcross. Considering both of these distributions there are 42 out of a total of 149 strains which show average heights within the range marked by the Kelly parent. Similarly, there are 48 average heights of strains of hybrid origin which fall within the range of the resistant 10 Ba parent.

DATA OBTAINED IN 1934

The planting in 1934 was a duplicate of that in 1933 except that some of the hybrid strains did not appear because seed of them was not available. The distributions of average heights shown in Table 2 are based on measurements made from July 24 to 27, inclusive, before any of the tobacco was in bloom.

TABLE 2.—*Frequency distributions of average height in inches of progenies obtained by selfing backcrosses of the F_1 to the Kelly parent and of the parent plants grown in 1934 at Lakin, W. Va.*

Name	Mid-classes in inches											
	8	9	10	11	12	13	14	15	16	17	18	19
10 Ba parent	–	–	–	–	–	–	–	–	–	–	–	1
Kelly parent	1	–	2	–	–	–	–	–	–	–	–	–
(Kelly x 10 Ba) x Kelly	–	–	–	–	3	4	8	10	7	12	14	11
(10 Ba x Kelly) x Kelly	–	–	–	–	–	–	1	–	3	–	1	1

Name	Mid-classes in inches												Total
	20	21	22	23	24	25	26	27	28	29	30	31	
10 Ba parent	–	–	–	2	–	1	–	–	1	–	–	–	5
Kelly parent	–	–	–	–	–	–	–	–	–	–	–	–	3
(Kelly x 10 Ba) x Kelly	10	11	8	3	6	3	7	1	2	4	0	1	125
(10 Ba x Kelly) x Kelly	3	1	2	–	–	–	–	–	–	–	–	–	12

The relative distributions for average heights of the parents are similar to those shown in Table 1. There is a distinct difference between the resistant and susceptible parent. The average heights of the strains of hybrid origin are in general similar to those obtained the previous year, but differ in their relation to the distribution shown by the parents in that a relatively large proportion (over one-half) of the average heights fall within the ranges of those for the resistant 10 Ba parent and none of them within the range of those for the susceptible Kelly parent. There were only 12 plats (three groups consisting of four replicates each) of the Kelly parent grown in 1934.

In 1934, as has been stated, three measurements of height of plant were made, the first from July 24 to 27, inclusive; the second from August 8 to 13, inclusive; and the third from September 6 to 10, inclusive. At the time the last measurement was made the percentage of plants not in bloom was determined. Correlation coefficients were computed (Table 3) showing the linear relations between these values for the 125 tobacco strains designated in Table 2 as (Kelly x 10 Ba) x Kelly.

TABLE 3.—*Interrelation of mean heights of tobacco determined at successive growth periods and the relation between the mean height of plant at first period and percentage of plants not in bloom at third period expressed as coefficients of correlation.*

Correlation between	n	r
Mean heights at first and second periods	125	+0.950
Mean heights at first and third periods	125	—0.040
Mean heights at second and third periods	125	+0.028
Mean height at first period and per cent of plants not in bloom at third period	125	—0.689

The significantly high correlation coefficient (+0.950) between the mean heights of the first and second measurements of the 125 strains of tobacco of hybrid origin indicates that the dwarfing effect of the

root rot organism persisted until the middle of August. The coefficient between the mean heights of the first and third measurements, and likewise between the second and third measurement, is sensibly zero. This indicates that the relative differences in mean heights which persisted up until the middle of August were for the most part overcome after that time. The recovery after mid-August may be partly attributed to relatively high soil temperatures during the last two weeks in July. It has been shown (1) that high temperatures impede progress of the root rot disease. No soil temperature records are available, but the average daily maximum temperatures by weeks for July and August during 1934 at Lakin are July 1 to 7, 89.9° F; July 8 to 14, 87.7° F; July 15 to 21, 96.3° F; July 22 to 28, 99.6° F; July 29 to Aug. 4, 87.1° F; Aug. 5 to 11, 89.3° F; Aug. 12 to 18, 87.3° F; Aug. 19 to 25, 83.0° F; and Aug. 26 to 31, 80.7° F.

The high negative correlation ($r = -0.689$) between the mean height at the first measurement and the percentage of plants not in bloom at the time of the third measurement may indicate the extent to which blooming was delayed by root rot infection.

DISCUSSION

There is some objection to using height of plant (3) as an index of susceptibility of tobacco to root infection by *Thielavia basicola*, because it is obvious that there may be additional causative factors operative to bring about dwarfing. It is believed, however, that the height measurements reported here are indicative of infection by the organism causing root rot. The parents, 10 Ba and Kelly, normally are of about the same height and flower at about the same time. The root rot organism *Thielavia basicola* was known to be present and the soil conditions were favorable (1) for a high incidence of the disease caused by the organism. The parents used in the cross showed a striking difference in growth (Fig. 1) in soil infested with root rot. Kelly, which was known to be susceptible, remained stunted throughout the whole of the growing period, but 10 Ba, the resistant parent, showed normal growth with no tendency to become dwarfed.

The first-generation crosses were backcrossed to the Kelly parent and the immediate resultant progeny self-fertilized. If a single main factor difference was operative in controlling inheritance of reaction to *T. basicola*, one would expect about one-half of the strains coming from the above-mentioned selfing to react in a manner similar to one of the parents; if two factor differences were operative, one-fourth of such strains should so react. As a matter of fact, in 1933, somewhat over one-fourth, and in 1934, over one-half of the strains of hybrid origin reacted in a manner similar to that of the resistant 10 Ba parent. The data are too meagre to make it worth while to speculate as to the number of factors concerned, but they do show that reaction to *T. basicola* in tobacco is inherited.

In 1932, the F_1 plants from the cross 10 Ba x Kelly were grown under conditions similar to those which have been described and for the most part were found to be resistant to root rot. This, together with the data presented in Tables 1 and 2, indicates that resistance

Fig. 1.—Kelly, on the right, and 10 Ba parents growing in adjacent rows at the Lakin Experiment Farm in 1932. Kelly, shows the dwarfing effect of root rot, *Thielavia basicola*.

behaves at least as a partial dominant, as has been reported by Johnson (2).

CONCLUSIONS

Resistance of tobacco *Thielavia basicola* is heritable as a dominant or partially dominant characteristic.

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THE INFLUENCE OF THE AWN UPON THE DEVELOPMENT OF THE KERNEL OF WHEAT[1]

C. E. Rosenquist[2]

AWNED varieties of wheat are rapidly replacing the awnless varieties in the United States. They have been generally reported to be better adapted than the available awnless varieties and to have produced over a period of years greater yields of grain In this connection the question arises whether the presence of awns upon florets of wheat causes an increase in weight of the enclosed kernels.

In 1889 and 1890, Hickman (4, 5)[3] reported an increase in yield of awned over awnless wheat. Over a period of 10 years using hundreds of varieties, the increased yield in favor of the awned varieties was 6 bushels per acre. About 26 years later, Fleischmann (1) isolated three types from native Hungarian wheat and propagated them further. Type A was awnless or slightly spurred, type B had awns as long as the glumes or shorter, and type C had awns longer than the glumes. Type A was generally inferior to the other two types, being lower in yield and producing lighter kernels. Type C was slightly better in most respects than type B and much better than type A. In 1919, Grantham (2) reported an increase of 3.31 bushels per acre in favor of awned wheat when 1,986 varieties were used in 26 trials. Treyakov (9), however, found that over a period of years at the Poltava station the awnless varieties outyielded the awned ones but individual grains from awned spikes were heavier than those from awnless spikes.

Several investigators have offered explanations for an apparent superiority of awned varieties. Perlitius (6) calls attention to the fact that awned cereal varieties under normal conditions ripen earlier than awnless ones. This, in many cases, might explain the differences in yielding ability. But he also says that the volume, weight, and ash content of the grain is increased by the transpiration of the awns. In some cases awned spikes transpired twice as much as either awnless ones or "de-awned" ones. Zoebl and Mikosch (11) in 1892 had already advanced this belief. They found that spikes of barley having awns transpired almost five times as much water as spikes from which the awns had been removed. These spikes were kept in distilled water having an oil film, the whole being weighed periodically. They also found that the greatest part of the water lost by the spike was through the awns and that the spikes transpired almost as much water as the upper three leaves of the culm. Vasilyev (10) reported results similar to those mentioned above. He varied his procedure in one case, however, when he cut off the awns from one-half of the spike and found that the kernels produced in these "de-awned" florets were 9% lighter in weight than those produced in awned florets.

In 1898, Schmid (7) wrote nine different articles on the structure and function of awns in the cereals. Using approximately the same method as that of Zoebl and Mikosch, he found transpiration from the spikes of many cereals, including

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[3]Figures in parenthesis refer to "Literature Cited," p. 287.

wheat, to be reduced one-sixth to one-third when the awns were removed from the cut-off spikes. The relative assimilation of awned vs. de-awned spikes was about 3:1, with much variation among the several cereals tested. The average weight of kernels from awned spikes was about 3.3% greater than that from de-awned spikes. When one-half of the spike was de-awned and compared with the other normal awned half, the difference in weight in favor of the awned kernels still remained 3.3%. In 1916, Tedin (8) compared plants of barley which had all the awns blown off the spikes shortly before ripening with normal plants in the same field. De-awned spikes ripened earlier and produced kernels whose average weight was 10% less than those on normal spikes. Eight varieties were used in this study. Harlan and Anthony (3) found kernels from spikes whose awns were clipped off to be lower in weight of dry matter and smaller in volume than those from normal spikes. This difference was not thought to be due to injury or the shock of removing the awns.

PRELIMINARY STUDIES INVOLVING INJURY TO FLORETS

In 1929, when experimenting with crossing technic in wheat, the author found kernels from spikes whose awns were clipped so low that part of the glumes was also removed to be smaller than those from normal spikes. Kernels from these "clipped" spikes weighed only 82.7% as much as those from similar awned spikes.

If kernels from "clipped" florets could be compared with those from homologous normal florets on the same spikes, errors due to variation in kernel size among different spikes could be avoided. Accordingly, all the spikelets on one side of several spikes were clipped at pollination time, while those on the opposite side of the same spikes were left untreated. The kernels from clipped spikelets weighed 85.1% as much as those from normal spikelets on the same spike. In another of these method studies the outer glumes only were removed from the spikelets of several awned spikes at about pollination time, while others were untreated. Kernels from spikes having the outer glumes removed weighed 92.1% as much as those from normal spikes. This suggests that even the outer glumes have an effect upon kernel size. This reduction in size is probably due to injury to and removal of nearby living tissue. That such is probably the case is indicated by the fact that Treyakov (9), Perlitius (6), Schmid (7), and Tedin (8) reported earlier ripening in the case of de-awned spikes

EXPERIMENTS INVOLVING NO INJURY TO FLORETS

METHODS

If, then, kernels from normally awned and awnless florets found on the same spike could be compared, errors due to injury, as well as those due to selection of spikes, could be greatly reduced if not entirely eliminated. However, error due to position of the kernel on the spike would thus be introduced for "upper" kernels are normally somewhat smaller than "lower" kernels. In order to eliminate this error, a somewhat complicated procedure was necessary.

The F_2 progeny of a cross between Garnet (a variety with spur-like awns on a few of the upper lemmas) and Prelude (a fully awned variety) was divided into three classes of segregates as determined by the character of awns on the spikes.

These were (a) awnless (similar to the Garnet parent), (b) fully awned, and (c) intermediate, i.e., having long awns on the upper lemmas, shorter ones near the center of the spike, and none on the lower half of the spike.

Spikes with intermediate awms were selected at random. These were matched, individually, with awnless spikes of similar character and having the same number of spikelets. In all, 121 spike pairs, including 2,741 upper and 3,411 lower kernels, were thus obtained for detailed study. All kernels from awned florets on an intermediate spike were removed and weighed. After the removal of each kernel an homologous kernel on the paired awnless spike was removed and treated in a like manner. Comparisons of weight of kernels from awned with those from awnless florets on the same spike were now possible and error due to position of the kernel on the spike could be avoided by indirect comparison with homologous kernels on spikes without awns. Since all spikes were F_2 progeny of a cross, varietal differences were eliminated.

COMPARISON OF KERNELS FROM AWNED AND AWNLESS FLORETS OF THE SAME SPIKE

It was found necessary to report the results of these experiments as ratios. As an example, the weight ratio of kernels from awned (upper) florets compared with those from awnless (lower) florets on the same spike may be 0.99 for an intermediate or partially awned spike. For a paired awnless spike using homologous kernels the ratio may be 0.97. This gives a plus deviation of 2% between the two ratios. There were 121 intermediate spikes and 121 corresponding paired awnless spikes used in this experiment. Tables showing individual data from the 121 spike pairs would be too cumbersome to include in this paper. The ratio of upper (awned) to lower (awnless) kernels found on spikes with intermediate awns was 0.981. The corresponding ratio for homologous kernels on awnless spikes was 0.967. The average of the plus deviations was 4.3 and of the minus deviations was 2.9. The difference of 1.4% with odds of 27:1 in favor of kernels from awned spikelets is thought to be significant. Odds were obtained by applying Fisher's "t" distribution formula to the plus and minus deviations. These data show that kernels from awned florets tend to be somewhat heavier than those from awnless florets produced on the same spike.

Compared with the pronounced differences reported in the literature and the results of a preliminary test reported in this paper, which showed kernels from normal florets to be 15% heavier than those from clipped florets, this difference of 1.4% is not very great. It must be borne in mind, however, that in the preliminary test the awns had been clipped at about the pollinating stage and injury to the spikelets clipped at this early stage no doubt caused most of this reduction in average weight of kernels from clipped spikelets. In the experiment with which this paper primarily deals, however, the florets were not injured and error due to differences in position of the kernels upon the spike was practically eliminated.

COMPARISON OF AWNLESS,[4] INTERMEDIATE, AND AWNED SPIKES WITHIN AN F_2 PROGENY

If awned florets in general produce relatively larger and heavier kernels than awnless florets, it follows that awned spikes of the F_2

[4]Having a few spur-like awns.

population should produce heavier kernels than awnless ones, and intermediately awned spikes could be expected to produce kernels intermediate in these respects. Table 1 reports the results of an experiment planned to test this assumption. Awned, intermediate, and awnless spikes were selected at random from the F_2. The kernels were removed and weighed. The average weight of kernels from 280 awnless spikes was 18.5 mgm; from 300 intermediate spikes, 19.1 mgm; and from 199 awned spikes, 19.4 mgm. Their respective relative weights were 100.0, 103.2, and 104.9. These data show that kernels from awned spikes of an F_2 population are heavier than those from only partly awned spikes and that these in turn are heavier than those from awnless spikes. In this F_2 population, then, the presence of an awn upon the lemma of a floret tends to increase the weight of the kernel produced in that floret. It would be interesting to determine how composite seed of awned segregates would compare in yield with that of awnless segregates in later generations.

TABLE 1.—*Average weight of kernels from awnless, intermediate, and awned spikes selected at random from the F_2 of the cross Garnet x Prelude.*

Type	Number of spikes	Number of kernels	Average weight per kernel, mgm	Relative weights
Awnless	280	7,563	18.5	100.0
Intermediate	300	8,258	19.1	103.2
Awned	199	5,632	19.4	104.9

SUMMARY

By comparing kernels from awned and awnless florets borne on the same F_2 spikes, errors due to injury and to varietal, plant, and spike differences were practically eliminated. Due to the fact that kernel size is somewhat dependent upon the position of the kernel in the spike, it was necessary to compare homologous kernels of awnless spikes with those of intermediately awned but similar "paired" spikes. It is thought that results obtained from this experiment express fairly accurately the influence of the awn upon the average kernel weight.

Kernels from awned florets were found to be about 1.4% heavier, as an average, than those from awnless florets in the same spike. Furthermore, kernels from intermediately awned F_2 spikes were, as an average, 3.2% heavier than those from awnless F_2 spikes, while kernels from fully awned F_2 spikes were 4.9% heavier. The presence of awns on the florets of wheat tends toward the production of heavier kernels.

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MARGINAL SOIL AND FARM ABANDONMENT IN CAMPBELL COUNTY, WYOMING[1]

T. J. DUNNEWALD[2]

DURING the summer of 1935 the Agronomy Department of the University of Wyoming, in cooperation with the Bureau of Agricultural Economics, U. S. Dept. of Agriculture, started a soil survey of Campbell County, Wyoming, collecting at the same time information in each township as to cultivated areas, abandoned farms, vegetation, and kinds of crops. Such data were collected in 21 townships and a soil map completed during the past summer. This paper attempts to report progress and some of the findings and observations so far obtained.

SETTLEMENT

The area lies 60 miles west of the Black Hills with an annual average rainfall of 16 inches. This has been sufficient some years to encourage dry farming. Communities of farms have developed all over the county, separated by long stretches of unbroken sod pasture land used only for grazing.

The total cultivated area has reached a maximum of 15 to 16%. Dry years have tended to discourage farming and during the past summer nearly one-third of the area once cultivated has been abandoned or bears no crops but weeds. Eighty-five per cent of the total area of the 21 townships surveyed is covered with short grass vegetation. When spring rains are frequent, good grass is obtained in valleys, swales, and bottomlands. The wild hay is cut and stacked every summer and fall for winter use.

OWNERSHIP

County records show that the land has passed almost completely into private ownership. Of 1,035 parcels of land or farms, only 41 are now classed as public land. Of the 994 farms, less than half, or 462, are partly cultivated. The rest are owned by investors, homesteaders, speculators, real estate firms, and future bona fide farmers who have as yet made no attempt to break the sod, improve the land, or develop it into farms. Each of the 462 parcels which are farmed averaged 124 acres of cultivated land during the past year.

CROPS

In 5 of the 21 townships a map was constructed showing the location and kind of crop on all of the cultivated land found in these townships. Wheat was the crop which first attracted dry farming during the war.

[1]Contribution from the Agronomy Department, University of Wyoming, Laramie, Wyo. Received for publication January 18, 1936. Credit is due the following persons for aid in collection of field data: T. J. Glassey, U. S. Bureau Chemistry and Soils; and John Brock and Conrad Rohrer, Agronomy Department University of Wyoming.

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Many farmers speak of 40 to 50-bushel yields of grain obtained during moist years. Corn also does well in moist years and is still the second most popular crop. The crops and their extent in percentage of the cultivated area during 1935 were as follows:

Crop	Acres	%
Wheat	3,390	29
Fallow	2,730	24
Corn	2,550	19
Rye	1,540	13
Oats	640	5
Barley	220	2
Alfalfa	200	2
Cane	130	1
Millet	110	1
Flax	30	1

SOILS

The soils in these townships were classified into 40 or 50 types, but for our purposes these may be grouped as (a) sandy loam soils, (b) medium to heavy soils, (c) red soils, and (d) rough stony or steep land.

The soils are chiefly residual in character, except along the streams, and are closely associated with the character of the parent rocks which are chiefly shales and sandstones and red clinker beds. The sandy loams occupy chiefly undulating to rolling country and low ridges projecting above the shales. These are the best dry farm soils for the average run of seasons. They are absorbent and porous and take up moisture rapidly from showers or melting snow. Where underlaid by heavier subsoils, the sandy loams serve as a moisture reservoir during dry spells and cultivation produces a dry surface mulch which prevents rapid loss by evaporation.

The medium to heavy soils are gray loams and clays which occupy the more level ground within the cultivated area. They tend to slick over during showers, producing a maximum run-off over the surface and a minimum absorption of moisture. In moist years these soils outyield the sandy loam soils, but in dry years the crops suffer more severely for lack of moisture. Corn, grain, and even grass tend to dry up and turn brown during the drought periods. Fall-seeded grain often does better than spring grain and matures before severe drought affects it.

The red soils are loams and sandy loams derived from the DeSmet clinker beds. These are layers of shale which have been burned red by the heat from burning coal beds. The clinkers are hard and flinty, resisting erosion, and occur on the tops of ridges and knolls capping the sandstones, chiefly in the west and northwest parts of the county. The clinkers produce a sandy surface soil with a heavy loam or clay loam subsoil which has good moisture-holding capacity.

All three of these soil groups are represented on the state experiment farm east of Gillette. Good crop yields have been obtained there and a fine grove of trees has been maintained all through the drought

years on the red sandy loam soils. Very little successful cropping has been obtained on the heavy, lower lying shale soils.

Rough stony and steep land, as the name implies, includes all stony, rough, and hilly lands. These are best adapted to grazing and cannot be cultivated successfully. Considerable blocks of such soils occur along the Powder River divide west of Gillette and bordering Pine Ridge along the east edge of the county.

MARGINAL LAND ON A SOIL TYPE BASIS

This is an area of mixed soil conditions in which are found soil types well adapted to dry farming under the climatic conditions imposed, together with some types occasionally adapted to crop production, and others distinctly best adapted to pasture or grazing at all times.

Judged by the amount of cultivation to date, not over 15 to 25% of the area surveyed is adapted to crop production, especially in periods of drought. The remainder of the area will always be best adapted for grazing except in years of abnormally large rainfall.

Dry farming has been attempted on enough types of soil so that the feasible ones are known. It would seem unwise to block off whole counties or even townships as marginal land and eliminate all crop production because the grazing area is a potential market for some of the products grown on the best soil in the neighborhood.

It is also expensive to maintain roads, schools, and local governmental activities where settlement is scattered and 25% or less of the soil can be successfully cropped over a period of years. However, none of these activities should be entirely dispensed with because a minor proportion of the soils are suitable for cultivation. Rather, it would be best to adapt the roads, schools, and governmental activity to a grazing type of agriculture. With large units in ranches and grazing land, the governmental units also should be large and inexpensive

Migration out of the area in dry years is paralleled by a local shifting of farmers from the poorest land to farms with better improvements and prospects. This is a natural measure of adaptation and conservation which nature imposes and perhaps cannot be interfered with.

On the other hand, it appears that grass land unsuited to crop production when broken up requires 8 to 10 years to re-establish the grass cover and in the meantime the forage is also lost.

A solution for the present wasteful trial and error method of bringing these lands into agricultural use would appear to be a classification of the lands adapted to cropping and some regulation device tending to prevent the continued breaking up of the grass sod on soils which are clearly better adapted for grazing than for crop production.

THE EFFECT OF CERTAIN MANAGEMENT PRACTICES ON THE AMOUNT OF NITROGEN IN A SOIL[1]

P. E. KARRAKER[2]

FROM 1923 to 1934, an experiment was conducted on the Kentucky Agricultural Experiment Station farm at Lexington in which small plats were handled or cropped as follows:

Plats 1 and 4 kept bare by scraping.

Plats 2 and 5 in continuous bluegrass.

Plats 3 and 6 in continuous bluegrass and white clover.

The plats were 16 feet square, were in a line, separated by 3-foot bluegrass strips, and were numbered consecutively.

In September, 1923, and again in the following February, plats 2 and 5 were seeded to bluegrass and plats 3 and 6 to bluegrass and white clover. White clover also was reseeded in plats 3 and 6 several times during the experiment.

Thru 1928, the vegetation on these plats was not disturbed except that it was removed when thought necessary to maintain the stand. The dates when this was done and the amounts of dry material and nitrogen removed are shown in Table 1. After 1928 the vegetation was clipped from time to time with a lawn mower and left on the plats.

Care was taken to remove any legume plants appearing in plats 2 and 5 but, in the main, the other volunteer plants which survived the clipping treatments were allowed to grow. The stand of bluegrass on these plats varied from good at the beginning of the experiment to fair at the close, but the bluegrass became rapidly less vigorous from the beginning of the experiment and, after 1928, the larger part of the growth was mainly volunteer annual grasses, particularly crabgrass. However, because of insufficiency of available nitrogen, none of the plants in these plats made vigorous growth after the first few years of the experiment.

Considerable sweet clover grew on plats 3 and 6 in 1925 until the middle of July when it was killed by cutting. It was left on the plats. Before cutting, it was 3 to 4 feet high and covered the ground fairly well. Other than the sweet clover just mentioned, the vegetation on these plats during the experiment was mainly bluegrass and white clover. Because of the several reseedings, white clover perhaps formed a larger part of the total vegetation than in the average bluegrass pasture but, in the main, the amount and composition of the plant growth on these plats was very similar to that in an average bluegrass pasture in this section. The comparatively vigorous growth of vegetation on these plats contrasted sharply with the weak growth on plats 2 and 5, particularly after the first few years of the experiment. The quantities of vegetable material removed from the plats on May 28, 1926, and May 25 and July 26, 1928 (Table 1) are comparable

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[1]The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station, and is published by permission of the Director. Received for publication February 1, 1936.

[2]Associate Professor of Soils.

TABLE 1.—*Air-dry material and nitrogen removed from the plats.*

Date of removal	Nature when removed	Pounds per acre removed	
		Dry matter	Nitrogen
	Plat 2		
May 28, 1926......	Green	879	10.2
Mar. 25, 1928.....	Dead material from previous year	2,552	27.8
May 25, 1928.....	Green	217	4.6
July 26, 1928......	Green	1,687	21.5
Total..........			64.1
	Plat 5		
May 28, 1926.....	Green	868	11.0
Mar. 25, 1928.....	Dead material from previous year	3,337	40.0
May 25, 1928.....	Green	154	3.3
July 26, 1928	Green	1,431	20.6
Total..........			74.9
	Plat 3		
May 1, 1926	Dead material from previous year	2,817	42.5
May 28, 1926.....	Green	2,810	42.9
Dec. 7, 1926	Most of top growth	2,684	35.9
Mar. 25, 1928.....	Dead material from previous year	3,124	65.8
May 25, 1928......	Green	266	8.1
July 26, 1928	Green	3,827	74.4
Total..........			269.6
	Plat 6		
May 1, 1926	Dead material from previous year	3,669	72.9
May 28, 1926	Green	1,995	33.9
Dec. 7, 1926.. ...	Most of top growth	3,721	53.0
Mar. 25, 1928.....	Dead material from previous year	4,674	65.4
May 25, 1928.....	Green	289	8.8
July 26, 1928	Green	3,084	51.6
Total..........			285.6

and indicate the differences in growth in these years. The total material removed from each of the plats at these dates in pounds per acre was as follows: Plat 2, 2,783 lbs.; plat 5, 2,453 lbs.; plat 3, 6,903 lbs., and plat 6, 5,368 lbs.

The soil on which these plats are located is a Maury silt loam. The pH is about 5.5. The phosphorus and potassium, determined in a composite sample of surface soil from an adjoining area, are 4,680 and 24,000 pounds, respectively, per 2,000,000 pounds of dry soil.

The plats were sampled for nitrogen analysis in September, 1923, October, 1924, and November, 1931. The 0 to 6 and the 6 to 18 inch layers were sampled. These were assumed to weigh 2,000,000 and 4,000,000 pounds per acre, respectively. At each time nine cores were taken from a plat. In 1924 and 1931, these were located 4 to 6 inches away and in opposite directions from those in 1923. The sampling in 1924 was done to check the nitrogen analysis of the previous sampling.

The 1923 and 1924 analyses are shown in Table 2. The average of these analyses, the analyses of the 1931 samples, and the changes in nitrogen from the 1923–24 to the 1931 samplings are shown in Table 3.

TABLE 2.—*Nitrogen in the soil of the plats in 1923 and 1924 stated as pounds per acre.*

Plat No.	0–6 inches		6–18 inches	
	1923	1924	1923	1924
1	2,883	2,796	3,964	4,112
4	2,905	2,799	3,482	3,402
2	2,735	2,760	3,408	3,400
5	2,843	2,838	3,572	3,512
3	2,914	2,914	3,618	3,620
6	3,007	3,073	3,928	4,228

TABLE 3.—*Nitrogen in the soil of the plats in 1923–24 and in 1931, and the change in nitrogen stated as pounds per acre; also, the average total nitrogen in the vegetable material removed from the plats*

Plat No.	0–6 inches			6–18 inches			0–18 inches		Av. total nitrogen in vegetable material removed
	Av., 1923–24	1931	Loss (—) or gain	Av., 1923–24	1931	Loss (—) or gain	Loss (—) or gain	Av. loss (—) or gain	
				Bare Scraped					
1	2,840	2,454	—386	4,038	3,880	-158	-544	—530	——
4	2,852	2,517	—335	3,442	3,262	-180	-515		
				Bluegrass					
2	2,748	2,580	—168	3,404	3,514	110	— 58	62	70.0
5	2,841	2,783	— 58	3,542	3,782	240	182		
				Bluegrass and White Clover					
3	2,914	3,006	92	3,620	3,732	112	204	405	278.
6	3,040	3,291	251	4,078	4,432	354	605		

The decrease in nitrogen in the plats kept bare and the increase in nitrogen in the plats in bluegrass and white clover will be noted. The average decrease in the former was at the rate of about 76 pounds per acre per year (counting from 1924) and the average increase in the latter at the rate of about 58 pounds per acre per year. An average of 277.6 pounds of nitrogen per acre also was removed from the latter two plats in vegetable material during the first part of the experiment. The greater increase in nitrogen in the soil of plat 6 than in the soil of the duplicate plat 3, in part at least, is because of the larger plant growth, particularly of legumes, in the former plat than in the latter.

Notwithstanding the absence of legume plants and the small growth of vegetation on plats 2 and 5, as an average, nitrogen remained about constant in the soil of these plats during the period. As an average of the two plats, 69.5 pounds of nitrogen per acre, also, were removed

from the plats in vegetable material. There is an appreciable difference between these duplicate plats in the change in amount of nitrogen in the soil between sampling dates for which there is no specific explanation. In both plats, also, the surface soil decreased in nitrogen, but the sub-surface soil increased in nitrogen.

The fact that nitrogen did not decrease in these plats probably is at least largely because the continuous grass cover, even tho not vigorous, prevented practically all nitrogen losses. The plats were almost level so that practically no erosion took place. The nitrogen added in precipitation also should be considered in this connection. In work done in another experiment, this was found to be about 10 pounds per acre from April 1, 1934, to April 1, 1935. Perhaps this is about the average amount of nitrogen brought down in the precipitation from year to year on the Experiment Station farm. It appears not to be necessary, in accounting for the maintenance of nitrogen in the soil of these plats, to assume that any appreciable amount of nitrogen was fixed non-symbiotically. On the other hand, obviously the findings do not preclude some addition in this way. However, the soil was too acid to be favorable for nitrogen fixation by azotobacter.

The plats were plowed the last of April, 1934, and seeded to Sudan grass the last of May. The crop was cut twice. The dry matter and nitrogen in each cutting was ascertained. This was done to find out the effect of the previous treatments on the amount of nitrogen available to a crop in the soil of the various plats. The data are shown in Table 4. The effect of the treatments on yield and nitrogen content of the Sudan grass can be seen in the table.

TABLE 4.—*Dry matter and nitrogen in the Sudan grass in pounds per acre.*

Plat No.	Cutting, July 31		Cutting, Oct. 2		Total, two cuttings	
	Dry matter	Nitrogen	Dry matter	Nitrogen	Dry matter	Nitrogen
1	2,720	27.7	1,337	10.2	4,057	37.9
4	2,244	24.5	1,100*	9.0*	3,344	33.5
2	3,434	33.3	1,854	14.3	5,288	47.6
5	3,706	39.3	2,281	16.2	5,987	55.5
3	4,080	51.0	2,866	20.0	6,946	71.0
6	4,386	70.6	3,417	27.3	7,803	97.9

*This plat apparently received an addition of nitrogenous material after the July 31 cutting, since the vigor and color of the growth indicated considerable available nitrogen. The dry matter and nitrogen in the table were calculated from the July 31 figures for this plat by using the ratio between the July 31 and October 2 figures obtaining for plat 1.

SUMMARY

From 1923 to 1933, small plats were handled in duplicate as follows on the Experiment Station farm at Lexington: (1) kept bare by scraping, (2) in continuous bluegrass, and (3) in continuous bluegrass and white clover. Sweet clover grew in the bluegrass-white clover plats in the first half of 1925 and an appreciable part of the vegetation in the bluegrass plats during the latter years of the experiment was volunteer nonlegume plants. Vegetation was vigorous on the bluegrass-white

clover plats during the experiment, but poor on the bluegrass plats after the first few years of the experiment. Vegetation was removed from the plats at certain times through 1928. Thereafter, the plats were clipped several times a year and the clippings left on the plats.

Nitrogen was determined in the 0 to 6 and 6 to 18 inch soil layers of the plats at the beginning of the experiment and again in 1931. The average change in nitrogen during this period in the soil of the plats to a depth of 18 inches was in pounds per acre for the bare plats, 530 lbs. loss; for the bluegrass plats, 62 lbs. gain; and for the bluegrass-white clover plats, 405 lbs. gain. The average amount of nitrogen contained in the vegetable material removed from the plats was in pounds per acre for the bluegrass plats, 70 lbs.; and for the bluegrass-white clover plats, 278 lbs.

The plats were plowed and Sudan grass grown in 1934 to determine the effect of the treatments on the amount of nitrogen available to a crop.

CAPILLARY CONDUCTIVITY DATA FOR THREE SOILS[1]

L. A. RICHARDS[2]

WHEN a soil transmits or conducts water, the flow takes place through a complicated but connected region of liquid water. It is convenient to express this flow as the product of a conductivity factor and the total water moving force, this latter being the vector sum of the forces arising from the pressure gradient in the water system and gravity.[3] Thus,

$$\text{Flow} = \text{Conductivity} \times \text{Water Moving Force.} \qquad 1$$

This well-founded empirical equation is sometimes referred to as the generalized form of Darcey's law and may be employed when the soil pore spaces are wholly or only partially filled with water.

For this latter case, i.e., when the soil is not saturated, it is evident the thickness of the water-conducting films, and hence the conductivity factor, will depend on the moisture content of the soil. Likewise, the pressure in the liquid water depends on the moisture content of the soil Referred to atmospheric pressure as the zero reference, the pressure in water in an unsaturated soil is negative and it will occasionally be desirable to use the term tension as a name for this negative pressure. Further, using the terms capillary tension and capillary conductivity will make it clear that water relations in unsaturated soil are being considered.

One has considerable freedom in defining and choosing units for the quantities occurring in equation 1. In the present article, the water moving force will be expressed in dynes per gram and the flow as the number of cubic centimeters of water which in 1 second cross a square centimeter area in the soil, this area being taken perpendicular to the direction of flow. The capillary conductivity as here expressed in c g s units is simply the volume of water which in 1 second crosses unit area perpendicular to the flow per unit water moving force.

The capillary conductivity is a function of the various soil parameters, but may be thought of as a variable factor in which we may group

[1]Journal Paper No. J-326 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 487. The curves shown in this article were included in a paper presented by the author at the annual meeting of the Society in Chicago, December 6, 1935. Received for publication February 5, 1936.

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[3]The gravity w. m. f. (water moving force) per unit mass is equal to g, the acceleration of gravity. The pressure w. m. f. per unit volume of liquid is equal to the pressure gradient in the liquid. Hence, the pressure w. m. f. per unit mass is equal to the pressure gradient divided by the density. In mathematical treatments of the dynamics of soil moisture these forces have been expressed as the gradients of the gravitational and capillary potentials (1, 3). We have the equation,

$$-\text{grad}\,\Psi' = -(\text{grad}\,p)/d = (\text{grad}\,t)/d, \text{ where } \Psi', p, t, \text{ and } d$$

are respectively the capillary potential, capillary pressure, capillary tension, and density of the soil water. Under conditions where we may assume d is equal to unity, we may write $-\Psi' = -p = t$, numerically. In moist soil Ψ' and p are negative while t is positive. Dimensionally, Ψ' is given as work per unit mass while p and t have the units of pressure which are force per unit area.

the many things we do not know about the way these parameters affect the moisture-transmitting properties of the soil.

Ohm's law, which is directly analogous to equation 1, has served as one of the primary foundations of applied electricity for about a century and yet physicists have only recently been able to calculate from fundamental data values for electrical conductivity which are in approximate agreement with experimental values. Similarly, for soils, it is not too optimistic to expect that at some time in the future, when certain given data on the composition and state of packing, we shall be able to calculate the capillary conductivity. In the meantime, however, we may use equation 1 and experimental values of the capillary conductivity for expressing soil moisture flow quantitatively.

SIGNIFICANCE OF CONDUCTIVITY DATA

There are as yet but scanty data available on the capillary conductivity. The author has previously (3)[4] given curves which indicate the way in which the conductivity of three soils depends on the capillary potential. Earlier published data (2) relating the moisture content to the capillary potential of these soils makes it possible to determine the relation between the moisture content and the capillary conductivity. The data in Table 1 were taken from the papers just cited and the curves in Fig. 1 show the way in which the conductivity changes with moisture content in these soils.

TABLE 1.—*Relation between moisture content and capillary conductivity.*

Capillary tension equivalent water column in cm	Moisture content per cent, dry basis	Capillary conductivity, seconds x 10^{11}
	Sandy Soil	
0	23	——
20.3	13	930
138	6.3	16.4
243	5.4	6.95
	Greenville Loam	
0	40.1	——
32.1	34	342
85.2	28.6	340
161	22.4	310
248	19.9	257
393	17.2	178
597	15.4	72.7
	Preston Clay	
0	68.5	——
14.3	63.3	460
149	42.2	3.28
27.1	59.0	135

The range of moisture contents for which experimental values were obtained should be extended in each case, but the significance of such data in predicting important moisture characteristics of soils is easily seen. Except for the intermediate point on the Preston clay curve, the

[4]Figures in parenthesis refer to "Literature Cited," p. 300.

data were taken as the moisture content was continuously decreased, but it is expected that a small hysteresis effect would not appreciably alter these curves.

The numbers at the ends of the curves indicate the corresponding tension in the soil water expressed as the number of cms of water column necessary to produce these tensions. The places where the

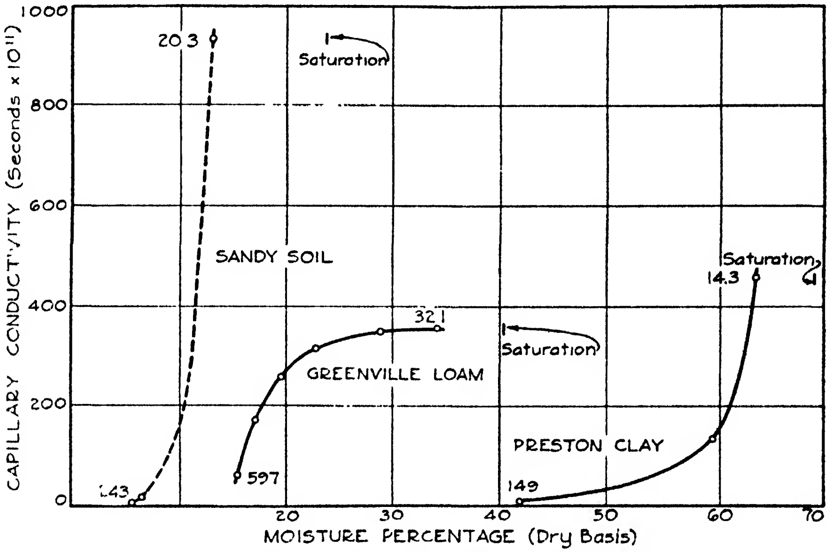

FIG. 1.—Curves showing the relation between capillary conductivity and moisture percentages for three soils: A, sandy soil; B, Greenville loam soil from the College farm, Logan, Utah; C, clay from Preston, Idaho. The numbers at extreme points on the curves indicate the corresponding capillary tension. Curve A is represented with a dashed line because the capillary tension-moisture percentage curve for a similar but not identical soil was used to transform the independent variable of the conductivity function from capillary tention to moisture percentage.

curves meet the moisture axis indicate the percentage at which the water in the soil is no longer present in a continuous liquid phase and capillary flow ceases. At the other extreme, when saturation is reached, the conductivity has its maximum value and no longer depends on the tension or pressure in the soil water. The temperature and state of packing of the soils were held constant during the conductivity determinations, but with due consideration of these factors such data may be applied to field conditions.[5]

An analysis of the curves yields such information as the following: Downward flow will keep the sandy soil A well drained because for moisture percentages above 13 the conductivity is high and allows the water to drain off quickly under the action of gravity. The conductiv-

[5]The first power of the reciprocal of the coefficient of viscosity of the capillary liquid is implicitly involved in the capillary conductivity as here used. Hence, the quantity will have a large temperature coefficient. For certain purposes it will be desirable to eliminate this viscosity factor and obtain a conductivity function, depending only on the liquid content and the composition and structure of the soil.

ity of the Greenville loam soil B remains fairly high even at the tension corresponding to a 590 cm water column, thus enabling this soil under certain conditions to raise appreciable quantities of water this distance from a water table. The low tension at the zero conductivity cut-off for the Preston clay C indicates that the maximum height to which water could rise by capillary action in this clay is 150 cm. On the other hand, the high moisture percentage at cut-off indicates that downward flow under the action of gravity would not reduce the moisture percentage below 40; hence, this clay soil will act as a good reservoir for precipitation.

With the soils for which data are given in this paper, the conductivity cut-off points were not actually reached, but it is seen that for the sand and clay soils used the conductivity values become small at moderately low tensions. It is evident that porous clay apparatus for measuring or controlling the capillary tension of soil can be successfully used only at moisture contents where the conductivity is appreciable.

SUMMARY

Curves are given which show the relation between the capillary conductivity and the moisture percentage for a sand, a loam, and a clay soil.

The relation of these curves to important moisture characteristics of soils, such as water storage, drainage, and maximum heights of capillary rise from a water table, is pointed out.

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STUDIES ON THE USE OF THE TERRACING PLOW FOR SOIL CONSERVATION[1]

Horace J. Harper[2]

THE terracing plow is an important agricultural implement because it can be used to build terrace ridges or it can be converted into a general purpose plow by replacing the terracing wing with a standard moldboard. One of the reasons why the terracing plow has not been used more extensively in the control of soil erosion is due to the fact that the terrace ridge cannot be completed in one operation. The loose soil must be packed by rainfall before it can be plowed a second time in order to increase the effective height of the ridge. Ramser,[3] in discussing the need of improving machinery for terrace construction, states that more than one plowing is needed to build a terrace ridge having a proper height. Smith[4] states that the terrace plow is effective for three rounds after which it acts like an ordinary plow, and that the small farmer who wishes to terrace a few acres can afford to consider this type of terracing equipment.

The cost of terracing tools has been one factor which has retarded the program of soil conservation in many areas. Although the cost of terracing equipment varies considerably, there are many farmers who are not able to purchase tools which are frequently recommended and used in terracing demonstrations. Since power is available on the average farm to operate a plow and since the average farmer can supply labor when he cannot supply capital, the terracing plow could be an important factor in the expansion of a soil conservation program which is seriously needed in many areas to reduce soil losses which occur as a result of the uncontrolled movement of run-off water.

EXPERIMENTAL

For several years studies have been in progress at the Oklahoma Agricultural Experiment Station in order to determine what methods should be used to reduce the rate of soil erosion on land which has been abandoned because it will not produce satisfactory yields of cultivated crops. The major portion of this land is low in fertility and unpalatable species of grass and weeds occur on these areas as a subclimax vegetation. Because of a lack of vegetative cover on these soils, erosion continues at a relatively rapid rate and small gullies develop into canyons with overfalls which are difficult to control. It was observed that the banks of shallow ditches are soon covered with

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[3]RAMSER, C. E. The need of improved machinery for terrace construction and farming terraced lands. Agr. Eng., 12:39–42. 1931.

[4]SMITH, H. P. Types of terracing machinery used in Texas. Agr. Eng., 12:43–44. 1931.

grass, but that enormous amounts of soil must be removed by erosion before the banks of deep gullies recede far enough from the center of the gullies so that grasses can establish a cover which will reduce the erosive effect of torrential rain.

An attempt was made to increase the growth of vegetation in several ditches in order that the soil which is removed from the banks by natural processes would be held by the grass and would gradually fill the ditch. A ditch-filling plow which is designed to move loose earth was used in some of these experiments, but the results were not satisfactory. The lower edge of the moldboard scraped the surface of the ground very much like a grader blade and interfered with the action of the plow in firm soil. The weight of the plow was also objectionable when it was necessary to lift the plow from one position to another in order to transfer a maximum amount of soil from the upper edge of the banks of crooked gullies into the bottom of the ditch. When this plow was used to construct a terrace ridge the soil was not discharged quickly from the end of the moldboard and a side draft developed which made the plow very difficult to handle.

Experiments conducted with a small terracing plow demonstrated that this tool was easier to handle than the ditch-filling plow and was more effective than an ordinary moldboard plow in moving soil laterally; consequently more soil could be transferred into a gully by operating the terracing plow along the edge of the bank. Although a terracing plow is a good tool to use in transferring surface soil into a gully, experiments have shown that the banks of a gully should not be disturbed until some provision is made to prevent run-off water from removing the loose soil which falls to the bottom of the ditch. Inexpensive barriers can be constructed to hold the soil until a good growth of vegetation can be established and in addition some method should be used to reduce the quantity of run-off water which enters the ditch under ordinary conditions

Contour ridges are very effective in reducing the quantity of run-off water occurring on overgrazed pastures or eroded fields which are not in cultivation and these ridges are easily constructed with a terracing plow. Small ridges having an effective height of at least 6 inches above the level of the ground after the soil is packed were built in six rounds with this implement. Run-off water cannot be controlled on steep slopes unless numerous ridges are constructed. When a walking plow similar to that shown in Fig. 1, No. 1, was used to build contour ridges, the third and fifth rounds were plowed in the subsurface soil. This soil contains fewer grass roots than the surface layer and it can be used to fill the openings between the sods to increase the effective height of the ridge in order that more run-off water may be held in the depression on the upper side of the contour furrows.

In some of the experiments soils were encountered which contained considerable amounts of clay, and when moisture conditions were not favorable for tillage, these soils would stick to the outer end of the straight terracing moldboard, as shown in Fig. 1, No. 1, and obstruct the movement of the soil from the furrow to the terrace ridge. It was also observed that this moldboard did not operate satisfactorily when sods were numerous and the plow could not be handled easily

on the inside of sharp curves in the furrow. In order to overcome this objection, the outer end of the straight moldboard as shown in Fig. 1, No. 1, was cut off and a flat piece of steel was attached at an angle

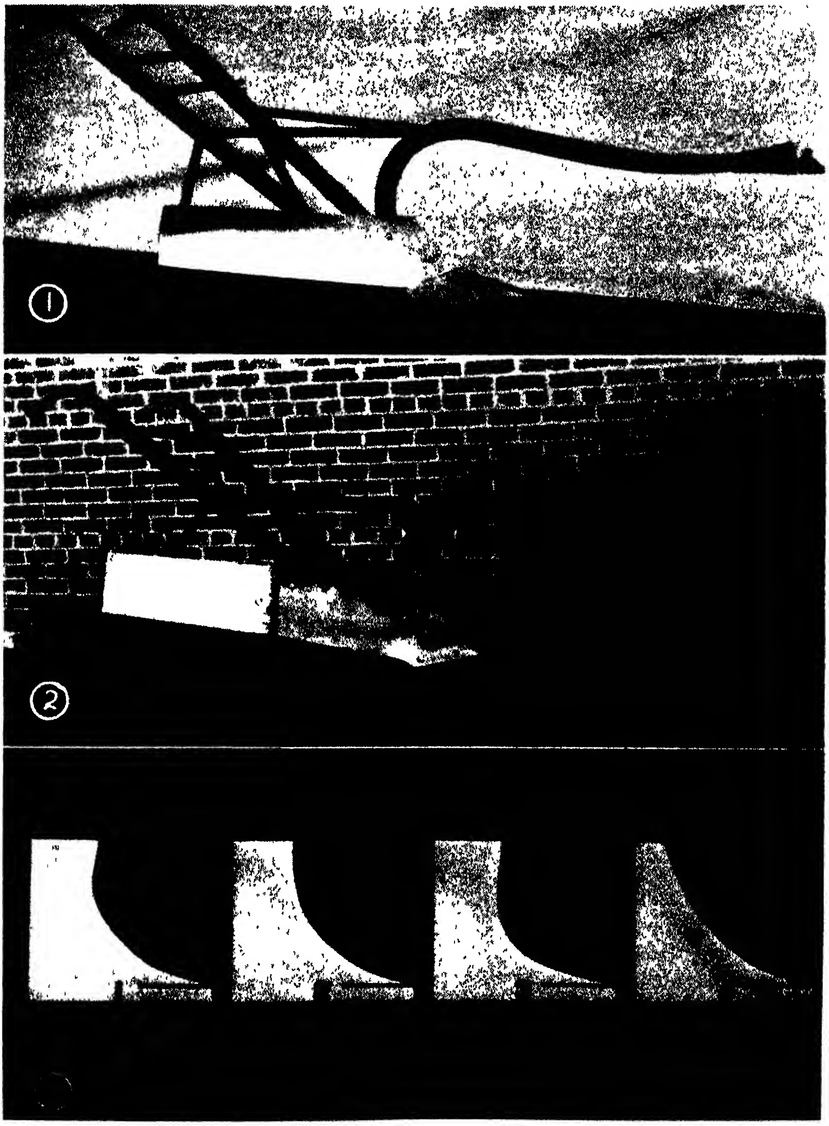

FIG. 1.—1, Terracing plow. 2, Terracing plow with modified moldboard. 3, Curvature of different moldboards, cross section shown from edge of share to top of moldboard 10 inches from landside. (1) Special terracing moldboard. (2) Regular terracing moldboard. (3) Moldboard on a mixed land plow. (4) Moldboard designed for black clay soils.

which would reduce the tendency for the soil to stick to the polished surface. The width of the moldboard was also increased by raising it 2 inches and welding a strip of steel to the lower edge of the moldboard where it fits against the share. The modified moldboard is illustrated in Fig. 1, No. 2. This change in the shape of the moldboard improved the operation of the plow in sticky soil, on sharp curves along contour ridges, and in plowing pasture contours where the sod did not pulverize easily.

A study of the design of terracing moldboards as compared with ordinary turning plows indicates that the terracing moldboard should have a higher lift than that which occurs on a general purpose plow. Fig. 1, No. 3, shows a cross section of four different plows which were studied in these experiments. The diagrams at the left which are marked 1 and 2 were taken from terracing plows which were used in these experiments and show the cross section from the edge of the share to the top of the moldboard at the point where the share and moldboard meet opposite the landside. Diagram 3 was taken from a general purpose moldboard and 4 from a plow designed to handle soils containing high percentages of clay. A "black land" plow is not satisfactory from the standpoint of building terrace ridges because it is not designed to lift the soil, although it scours better than an ordinary plow in compact clay soils. The problem of scouring is also associated with the steel which is used in the construction of the moldboard. The use of soft center steel in the construction of the terracing moldboard would improve the operation of the plow in sticky soil.

Fig. 2, No. 1, shows a terracing moldboard which has been attached to a riding plow. The long wing is very effective in moving loose soil toward the terrace ridge. This arrangement has some advantages over the walking plow equipped with a terracing moldboard, especially in clay soils where it is sometimes difficult to hold the walking plow in the ground when the outer end of the moldboard comes in contact with large masses of soil which do not pulverize readily. Fig. 2, No. 2, shows a riding plow equipped with a straight terracing moldboard. This plow can be used to build terrace ridges in soils which contain enough sand to cultivate easily. Fig. 3, No. 1, shows an overgrazed pasture which has been protected from surface erosion by the construction of contour ridges. A close spacing of the ridges is desirable in order to retain as much of the rainfall as possible and reduce the damage which occurs from run-off water. The terrace ridge in Fig. 3, No. 2, has been plowed once. Soil should be moved toward the ridge each time the land is plowed in order to increase the width and height of the barrier which is needed to protect cultivated land from run-off water.

When terrace ridges are built with a plow the area of subsurface soil which is uncovered is negligible as compared with conditions which exist after a grader or a V drag has been used. Frequently the major portion of the top soil is removed from strips of land several feet wide on each side of the terrace ridge when a grader is used to build the ridges. Because of the high clay content and lower amount of organic matter in the subsurface soil, poor crops are produced on the denuded areas for several years. When terrace ridges are con-

structed with a terracing plow, only the dead furrow between the ridges will suffer if the soil is moved toward the ridge each time the land is plowed.

Studies on the draft of the terracing plow indicate that the power required is similar to that of an ordinary plow when the soil is being moved laterally. The results of these experiments are given in Table 1.

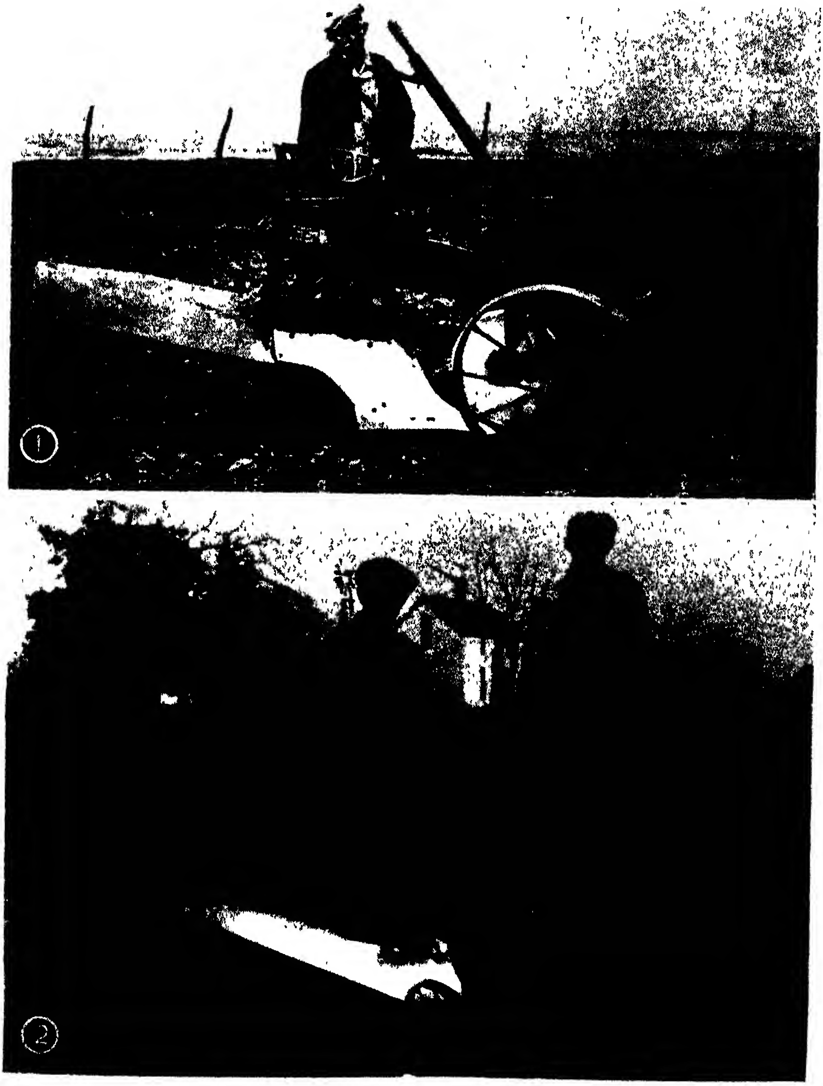

FIG. 2.—Experimental studies on terracing plows. 1, Modified terracing moldboard attached to a riding plow. 2, Regular terracing moldboard attached to a riding plow.

TABLE 1.—*Studies on the draft of a general purpose plow as compared with a terracing moldboard attached to the same share; data on the draft of a small terracing plow also included.*

Test No.	Soil type	Surface or subsurface soil	Drawbar pull in pounds per square inch of cross section of the furrow slice		
			14-inch share, ordinary moldboard	14-inch share, terracing moldboard	10-inch share, terracing moldboard
1	Derby sand	Surface	4.58	5.76	7.00
2	Derby sand	Subsurface	——	10.71	16.80
3	Vernon clay loam	Surface	8.57	7.85	10.00
4	Vernon clay loam	Subsurface	15.71	11.78	19.80
5	Kirkland fine sandy loam	Surface	5.00	6.28	5.13
6	Kirkland fine sandy loam	Subsurface	14.84	14.84	19.55
7	Kirkland fine sandy loam	Surface*	9.43	10.71	11.00
8	Kirkland fine sandy loam	Subsurface	17.46	14.50	19.55

*Native pasture; all other areas were in cultivation.

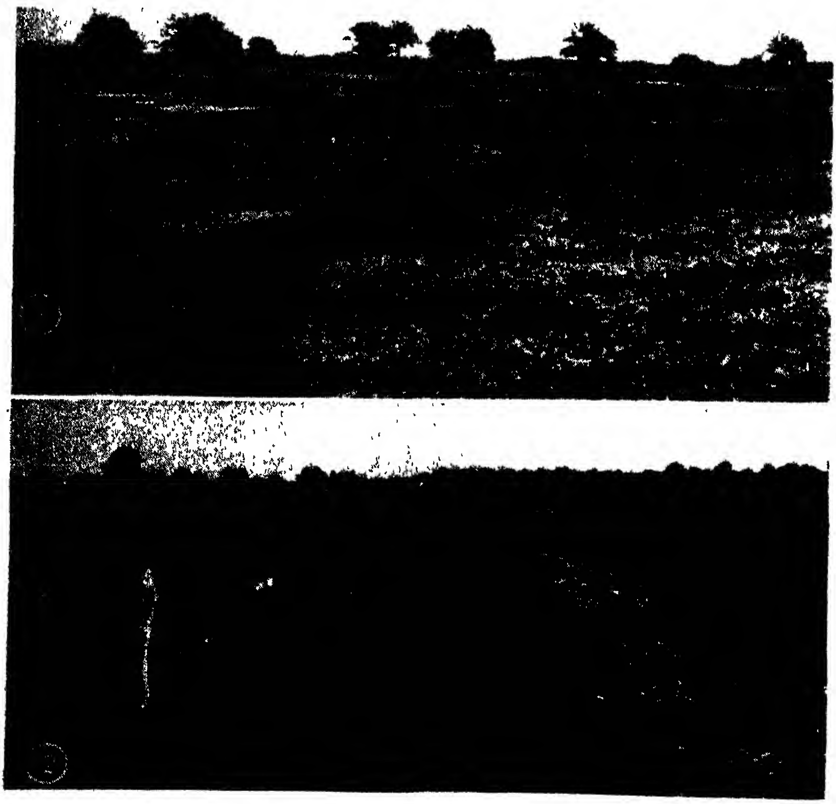

FIG. 3.—Studies on soil conservation. 1, Contour furrows protecting over-grazed pasture from erosion. 2, Building the terrace ridge with a terracing plow.

Some variation occurred in the depth of the surface and subsurface furrows in the different soil types and this may account for some of the differences in drawbar pull which were obtained in this experiment. The depth of the surface furrows varied from 5 to 6 inches, and the subsurface furrows varied from 4½ to 5½ inches. A walking plow was used in this experiment and was operated twice in the same furrow by shifting the hitch on the end of the beam. All measurements were made with an oil pressure dynamometer.

A considerable increase in draft occurs when the terracing plow is operated at a depth of 10 inches and the soil is raised toward the top of the terrace ridge. Data on the 10-inch terracing plow were included in this experiment, although no information was obtained to show the relative difference between the draft of this plow as compared with an ordinary moldboard attached to the 10 inch share. For some reason the draft per square inch of cross section of the furrow slice was greater when the 10-inch plow was used as compared with results obtained with the 14-inch terracing plow. A considerable amount of soil fell over the upper edge of the terracing moldboard when the 10-inch plow was used, which would indicate that the quantity of soil which was being moved was greater than the plow was designed to handle. It is interesting to note that the draft of the terracing moldboard attached to the share of the walking plow was frequently lower than the draft of the same plow equipped with a general purpose moldboard. The force required to move loose soil laterally is evidently small as compared with the power needed to cut and lift the furrow slice. About twice as much energy was required to pull the plow when it was operating in the subsurface soil. The higher clay content of the subsurface layers and the greater lift which was required to push the soil onto the terrace ridge was responsible for this condition.

Further studies on the draft of four different types of terracing plows were made on a deep sandy soil and these results are given in Table 2. Plow No. 1 and plow No. 2 were obtained from companies who sell terracing plows, while plows Nos. 3 and 4 were equipped with special moldboards which were designed to improve the operation of the plows under certain soil conditions.

TABLE 2.—*A comparison of the draft of different terracing plows operating in a fine sandy loam soil.*

Plow No.	Width of share in inches	Drawbar pull in pounds per square inch of cross section of furrow	
		Surface soil, 0 to 6½ in.	Subsurface soil, 6½ to 13 in.
1	10	8.15	14.92
2	10	8.15	——
3	12	7.69	11.54
4	10*	7.50	12.87

*Special moldboard as shown in Fig. 1, No. 2.

There is some evidence to show that plows Nos. 1 and 2 had a slightly higher draft than plows Nos. 3 and 4. Plow No. 2 was equipped with a moldboard similar to that shown in Fig. 1, No. 2, except

TABLE 3.—*A comparison of the draft of different terracing plows operating in a soil having a compact clay subsoil.*

Plow No.	Width of share in inches	Drawbar pull in pounds per square inch of cross section of furrow	
		Surface soil, 0 to 6 in.	Subsurface soil 6 to 10 in.
1	10	11.90	32.67
2	12	10.26	35.40†
3	10*	9.63	31.43

*Special moldboard as shown in Fig. 1, No. 2.
†Furrow depth, 0 to 7 inches in surface and 7 to 12 inches in subsurface soil.

that the moldboard was made in one piece. Three of these plows were compared on a shallow soil which had a very dense, compact clay subsoil and the results of this test are given in Table 3.

The most important information which was obtained in this experiment was the enormous increase in power required to move the subsurface soil as compared with the power required to turn the surface layer. It was quite evident that the large plow was more effective in handling the compact subsurface soil than the smaller plows. This information may be of some value in the development of a plow which can be used to terrace soils which are high in clay content.

The draft of a small terracing machine equipped with a 7-foot blade and set at a sharp angle to cut a furrow slice varied from 1,660 to 1,725 pounds when the point of the blade was cutting about 3 inches deep. A special 14-inch terracing plow operating in the same soil at a depth of 6 inches had a drawbar pull of 710 pounds. When this plow was moving a furrow slice from the subsurface soil at a depth of 6 to 12 inches, which was the second round in the same furrow, the drawbar pull was 1,375 pounds.

When a riding plow is used, it is necessary to plow a deep narrow furrow in order to build a terrace ridge of maximum height in one operation. Although the ridge which is built by one plowing is relatively narrow, it can be plowed a second time as soon as rainfall packs the soil. If small grain is planted on the area a second plowing can occur as soon as the roots of the plants are large enough to hold the soil together. Even though some of the ridges are broken by run-off water during periods of excessive rainfall, very little erosion will occur between the terrace ridges when the surface of the ground is covered with vegetation.

Low terrace ridges are more effective in controlling erosion on small fields than on large fields; however, the terracing plow is not limited to small fields with gentle slopes. There is no reason to believe that tractor plows can not be equipped with terracing moldboards and the job of terracing accomplished at the same time the land is plowed in order to reduce the cost of construction.

The terracing plow may also be used to mark the contours on land where soil erosion is controlled by strip cropping. On fields where the slope is not too great many small terrace ridges should be more effective in the conservation of rainfall than a few large ridges which

actually increase the slope of the land because of the deep ditches which are dug in order to build the terrace ridge.

Soil conservation is a problem which must be solved in most cases by the individual who owns or operates the land. A program of education must precede field operations. Enough evidence has been obtained in this investigation to show that the terracing plow can be used to control run-off water effectively from cultivated fields and overgrazed pastures when the slope of the land does not exceed 6 or 8%.

SUMMARY

Studies on the terracing plow were made to determine its limitations in a soil conservation program. It is an inexpensive tool and can easily be operated by the power available on the average farm.

It was found that the effective height of terrace ridges could be increased by plowing twice in the same furrow for three or four rounds. When a riding plow is used, a deep narrow furrow slice should be moved toward the terrace ridge.

A moldboard designed with the outer end flattened and bent slightly to the rear at a point about 22 inches from the edge of the landside will operate easier along crooked furrows, in soil where sods are frequently encountered, and in soil which tends to stick near the end of a straight moldboard

The draft of a terracing plow is very similar to that of a general purpose plow when operating under similar conditions.

A plow operating in subsurface soil required about twice as much power as the same plow operating in surface soil.

When terrace ridges are being constructed with a terracing plow, the land should be planted to small grain or some other crop which will cover the surface of the ground and reduce the erosion which may occur from breaks in the low ridges, unless the ridges can be plowed two or three times during the fall or winter in order to increase the effective height. When row crops are grown, the rows should be planted on a contour and parallel with the terrace ridge.

The terracing plow was more useful than a back-filling plow or an ordinary plow in gully control work where soil is removed from the upper edge of a bank in order to establish a more vigorous growth of vegetation in the bottom of the ditch.

THE EFFECT OF DIFFERENT PLANT MATERIALS, LIME, AND FERTILIZERS ON THE ACCUMULATION OF SOIL ORGANIC MATTER[1]

L. M. TURK AND C. E. MILLAR[2]

THAT the soil organic matter affects the chemical, physical, and biological properties of the soil is well known. The effects of added organic matter are usually favorable, but temporary adverse effects may result from the application of large quantities of organic matter having either an extremely narrow or wide carbon-nitrogen ratio. In the former case, toxic concentrations of ammonia or nitrate may accumulate and large losses of nitrogen are apt to result; whereas with an extremely wide ratio, nitrate deficiencies may occur. A desirable balance between carbon and nitrogen must be established before satisfactory crop yields can be expected. A desirable carbon-nitrogen ratio is one which permits the organic matter to decompose with the liberation of just sufficient nitrogen to meet plant requirements.

Long-time experiments[3] show that crop yields can be maintained by the use of mineral fertilizers, including nitrogen, and that at the same time the organic matter content of the soil may be increased. Similar plats receiving organic matter additions yielded no more in spite of the fact that the content of soil organic matter was considerably higher. In other words, soil treatments producing the largest accumulation of organic matter do not necessarily produce the largest yields of crops.

It is logical that the effect of added soil organic matter on crop yield depends upon the predominating effect, i.e., whether chemical, physical, or biological. The common plant nutrients supplied by organic matter may be supplied by fertilizers and when its predominating effect is chemical, fertilizers may effectively replace organic matter. Physically, organic matter increases water retention and fertilizer cannot replace it from this standpoint. Biological activity increases CO_2 production which increases the solubility of minerals and it is therefore tied up with the chemical effect. The "effect" predominating in any case is largely dependent upon the effective climate. Jenny,[4] in discussing the practical aspects of the nitrogen-climate relationship made the following comments: "Concerning this problem of increasing the nitrogen content of the soil by green manuring and similar methods. the nitrogen-climate relationship leads to the following suggestions: It seems to be possible to build up the nitrogen content of cultivated soils in the North by adding organic material because the low temperature would favor its preservation. In southern

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Authorized for publication by the Director as Journal Article 253 n. s. of the Michigan Agricultural Experiment Station. Received for publication February 3, 1936.

[2]Research Assistant and Head of Department, respectively.

[3]THORNE, C. E. The function of organic matter in the soil. Jour. Amer. Soc. Agron., 18:767–793. 1926.

[4]JENNY, H. Study on the influence of climate upon the nitrogen and organic matter content of the soil. Mo. Agr. Exp. Sta. Res. Bul. 152. 1930.

latitudes, however, it will be rather difficult, if not impossible, to increase permanently and profitably the nitrogen content of cultivated soils to the forementioned level (virgin level) by such practices because the high temperature militates against organic nitrogen accumulation by favoring decomposition."

"Recently, the term 'nitrogen turn-over' has been suggested, a term which refers to the amount of nitrogen that may be supplied to crops from rotation to rotation by means of crop residues, green manures, farm manures, and commercial manures. It seems probable that in the southern two-thirds of the United States at least, crop production will be maintained or increased by a control of this nitrogen turn-over rather than by an attempt to maintain the total nitrogen content at a particularly high level."

In the South, with warm, moist soil conditions, chemical and biological influences of organic matter are at a maximum. Under similar conditions the physical effect exerted by organic matter at any one time would not be great due to its small quantity. In the northern states where there are greater organic matter accumulations, its physical effects are more pronounced, and due to a slower rate of decomposition extending over a shorter favorable seasonal period, the chemical and biological effects are less potent. Particularly have the physical effects of soil organic matter been observed in the more sandy soils.

The yields of potatoes, various fruits, and truck crops in Michigan are limited, in general, because of insufficient soil moisture and there appears to be a close relationship between content of soil organic matter and the yield of these crops. Since these crops are grown primarily on the more sandy soils of the state, the problem of soil moisture is one of prime importance, which in turn, raises the question as to the most desirable method of adding organic matter to these soils. The primary object of this investigation was to determine some of the factors which affect building up the organic matter and nitrogen content of the lighter soils of Michigan. Considerable choice may be exercised in selecting green-manure crops (including crop residues) which may be incorporated into the soil, and in addition fertilizer and lime may be used with crop residues if they increase the accumulation of organic matter.

PLAN OF INVESTIGATIONAL WORK

In this experiment crop residues of various kinds and combinations were used, with and without the addition of fertilizer and lime. These materials were added to a Hillsdale sandy loam soil, as shown in Table 1, in 1-gallon jars in the greenhouse. The soils were brought up to a favorable moisture content (about one-third the maximum water-holding capacity) at various, although not regular, intervals throughout the experiment. The organic materials were added on the basis of air-dry weight. About 3 inches of stem were included with the alfalfa and sweet clover roots in order to duplicate closely field cutting by machine. Before thoroughly mixing the organic materials with the soil, they were air-dried and ground to a reasonably fine state. The soils were mixed once every 2 months.

Analyses were made for total carbon, total nitrogen, nitrates, and total combustible loss (loss on ignition) at the beginning of the experiment and at the end of each 4-month period thereafter for 2 years. Total carbon was determined by the use of a Fleming combustion furnace and ascarite absorbent; total nitrogen by the Kjeldahl method; nitrates by the reduction method (using Devarda's alloy), and combustible loss by using a muffle furnace. At the end of 2 years the moisture-holding capacities of the soils were determined by the Hilgard cup method and the moisture equivalent determined by the method of Bouyoucos.[5]

RESULTS

The carbon contents of the soils at the beginning of the experiment are shown in Table 1, together with the carbon contents found at other sampling periods. In cases where 20 tons of organic material were added, the original carbon content of the soil was increased approximately 0.7% (column 2) with all the plant materials except muck which increased the carbon supply by almost 0.9%. Muck is largely plant material in an advanced stage of decomposition and it has a realtively high carbon content. The 40-ton application of the various plant materials increased the carbon content of the soils from 1.13 to 1.50%. The values given in Table 1 (column 3) show that significant organic matter decomposition occurred in all soils during the 2-year period, except in the untreated soil and in those soils to which muck alone was applied. The 5% loss of organic matter in the latter case is not significant when compared with the 30 to 40% loss which occurred with most of the other treatments. Relative to the original amount of organic matter in the soil (as measured by combustible loss), there was a greater percentage loss at the end of 2 years in soils to which straw was added alone than in soils to which alfalfa or sweet clover was added alone.

The quantities of organic matter remaining for each soil (relative to the check) are given in Table 1 (column 4). Here again, the slow rate of muck decomposition in contrast to a very rapid disappearance of the other materials is noticed. A better representation of the losses of the added organic matter is presented in column 5. In calculating these values, the quantity of organic matter found in the "check" (no treatment) soil was subtracted from the quantity found in the treated soil both at the beginning and the end of the experiment in each case. With the exception of the muck treatment, less than 32% of the added organic matter remained at the end of 2 years even where 40 tons per acre of dry material were added.

Greater losses occurred with materials of low-nitrogen content which shows the importance of nitrogen in retaining carbon in the soil. This bears out the contention of Russel and Sievers[6] that it is necessary to add nitrogen to soils in order to increase appreciably the

[5]Bouyoucos, G. J. A comparison between the suction method and the centrifuge method for determining the moisture equivalent of soils. Soil Science, 40: 165–170. 1935.

[6]Russel, Sir E. J. Soil Conditions and Plant Growth. New York: Longmans, Green and Co. Ed. 6. 1932. (Pages 364–365.)

Sievers, F. J. Further evidence concerning the significance of nitrogen in soil organic matter relationships. Jour. Amer. Soc. Agron., 22:10–13. 1930.

TABLE I.—*Carbon and organic matter relationships in soils variously treated.*

No.	Soil treatment* — Materials and amounts	Total carbon at start %	Combustible loss as % of — Original amount‡	Combustible loss as % of — Check	Added organic matter left at 24 months %	Total carbon as % of — Original amount‡	Total carbon as % of — Check	Added carbon left % — End of 24 months	Added carbon left % — End of 4 months	Total carbon as % of original, 20 months	Organic matter, per cent total carbon, end 24 months†
1	No treatment	1.08	101	100	—	94	100	—	—	96	—
2	20 tons straw	1.78	66	113	18	67	117	25	41	67	1.72
3	20 tons alfalfa roots	1.69	70	121	29	75	125	41	64	76	1.91
4	20 tons muck	1.87	95	152	86	98	180	103	99	99	1.49
5	20 tons sweet clover plants	1.73	68	117	23	72	122	34	43	72	1.74
6	20 tons straw+500 lbs. $(NH_4)_2SO_4$	1.77	66	115	20	67	118	26	40	68	1.94
7	20 tons straw+500 lbs. $CaCN_2$	1.78	67	114	20	68	119	27	44	70	1.74
8	20 tons straw+20 tons alfalfa roots	2.45	59	135	27	56	136	27	43	57	2.24
9	10 tons straw+10 tons alfalfa roots	1.74	69	113	20	70	119	29	41	71	1.60
10	20 tons straw+20 tons muck	2.58	72	170	51	75	192	62	68	76	1.75
11	10 tons straw+10 tons muck	1.77	84	138	58	85	149	71	95	86	1.81
12	20 tons straw+20 tons sweet clover tops	2.21	59	138	28	65	142	37	51	66	2.10
13	20 tons alfalfa roots+3 tons lime	1.67	68	118	24	76	125	43	55	77	1.66
14	20 tons sweet clover plants+3 tons lime	1.76	67	114	20	70	121	32	42	72	1.54
15	20 tons straw+20 tons alfalfa roots +3 tons lime	2.46	54	131	21	58	141	30	55	59	1.75
16	10 tons straw+10 tons alfalfa roots +3 tons lime	1.72	65	117	21	71	120	32	51	72	1.98
17	20 tons alfalfa plants+3 tons lime	1.70	72	121	31	73	121	35	56	73	2.29

*Treatments represent rates per acre.
†Quantities found in check deducted in each case.
‡"Original amount" refers to the quantities originally present after making the soil treatments.

organic matter content. It is obvious, however, that inorganic nitrogen additions will not increase organic matter content unless accompanied by carbon.

Nitrogen fertilizer added to straw increased the accumulation of organic matter and carbon slightly. Since the quantity of nitrogen added with the straw was so small, measurable differences could hardly be expected. In most cases lime increased decomposition considerably, except in the case of the 10-ton application of straw plus the 10-ton application of alfalfa roots (treatments Nos. 9 and 16, column 5, Table 1). Total conbustible loss is not an absolute measure of the quantity of organic matter in the soil, but in this experiment one soil was used throughout and the results are therefore comparable to those of the total carbon method as is shown in columns 3, 4, 6, and 7 of Table 1. There are significant differences in the quantity of organic matter remaining, however, as revealed by the two methods (comparing values in columns 5 and 8). Soil treatment No. 3, for example, shows 29% of added organic matter present (column 5) as measured by total combustion, whereas 41% of the carbon was present (column 8). Treatment No. 17 had 31% of the added organic matter and 35% of the added carbon at the end of 2 years. When the carbon-organic matter factors are calculated from the carbon and organic matter remaining from the plant materials, they are found to vary from 1.49 to 2.29 (column 11, Table 1), which indicates the futility in ascribing any one value to a so-called carbon-organic matter ratio. A much more reliable expression is carbon.

The question may be raised as to whether the differences (column 11, Table 1) will persist for any great length of time. As time goes on the ratios will tend to reach the same value, but the process is slow. The organic matter in the soils in this investigation was decomposing very slowly after 2 years, as may be readily observed by comparing the data presented in columns 6 and 10 of Table 1. Very little decomposition occurred during the last 4 months of the test period which shows that the added organic materials had arrived at a rather stable state. Immediately following organic matter additions to the soil, a very rapid loss of carbon occurred in the presence of favorable environmental factors (column 9, Table 1). In several instances nearly 60% of added carbon disappeared within 4 months.

The carbon-nitrogen relationships in these soils as they existed at the beginning and at the end of the experiment are shown in Table 2. The data in column 2 show the percentage of total nitrogen in each soil at the start, while column 3 shows the quantities of nitrogen, expressed as milligrams per 100 grams of dry soil, gained or lost during the 2 years. In arriving at the latter values the accumulation of nitrate nitrogen was taken into consideration. The gains and losses of nitrogen are insignificant except for treatments Nos. 4 and 14 in which a loss of 12.0 and 16.6 milligrams occurred, respectively; and for treatments Nos. 12 and 17 in which a gain in nitrogen of 11.3 and 15.9 milligrams occurred, respectively. No explanation can be offered for these differences. The other differences are within the experimental error of the total nitrogen determinations. On the whole, these results do not show that significant quantities of nitrogen were fixed by non-

TABLE 2.—*Carbon and nitrogen relationships in soils variously treated.*

Soil treatment*		Total nitrogen at start %	Gain or loss in nitrogen, mgms per 100 grams soil†	Total nitrogen as % of‡		C:N ratio at start	C:N ratio at end of 24 months	C:N ratio relative to ratio at start
No.	Materials and amounts			Original amount§	Check			
1	No treatment	0.081	+0.4	96	100	12.7	13.1	103
2	20 tons straw	0.098	—0.2	92	116	17.6	13.2	75
3	20 tons alfalfa roots	0.128	+1.3	89	147	12.9	11.1	86
4	20 tons muck	0.132	—12.0	89	152	13.8	15.6	113
5	20 tons sweet clover plants	0.126	+3.4	85	138	13.4	11.6	87
6	20 tons straw+500 lbs. $(NH_4)_2SO_4$	0.101	+0.3	94	123	17.0	12.6	74
7	20 tons straw+500 lbs. $CaCN_2$	0.098	—1.3	93	119	17.5	13.1	75
8	20 tons straw+20 tons alfalfa roots	0.141	—1.2	86	156	17.0	11.4	67
9	10 tons straw+10 tons alfalfa roots	0.113	—1.6	90	132	14.9	11.8	79
10	20 tons straw+20 tons muck	0.141	+0.1	93	170	18.0	14.8	82
11	10 tons straw+10 tons muck	0.114	—2.1	92	135	15.1	14.4	95
12	20 tons straw+20 tons sweet clover tops	0.137	+11.3	90	159	15.7	11.6	74
13	20 tons alfalfa roots+3 tons lime	0.126	+4.8	86	140	12.9	11.7	91
14	20 tons sweet clover plants+3 tons lime	0.131	—16.6	78	131	13.1	12.1	92
15	20 tons straw+20 tons alfalfa roots+3 tons lime	0.138	—0.1	89	159	17.3	11.6	67
16	10 tons straw+10 tons alfalfa roots+3 tons lime	0.112	+5.0	91	132	14.8	11.9	80
17	20 tons alfalfa plants+3 tons lime	0.123	+15.9	90	143	13.4	11.1	83

*Treatments represent rates per acre.
†Gain or loss in total nitrogen in 24 months, as accounted for in total nitrogen analyses and nitrate determinations.
‡This does not include nitrate nitrogen.
§See footnote on "original amount", Table 1.

symbiotic organisms. If such fixation did occur, it was offset by losses due to volatilization.

The data in columns 6 and 7 (Table 2) show that the carbon-nitrogen ratio of each soil has become more narrow except in the untreated soil and the soil to which muck alone was added. The ratios were wider in soils receiving an application of lime than in the corresponding unlimed soils. The ratio in each case was narrowed to a value equal to or below that of the check soil except in soils treated with muck alone or in combination with other organic residues and soils in which straw was used alone. In cases where 20 tons of organic material were added, it is observed that the greatest percentage change (decrease) in carbon-nitrogen ratio occurred with low-nitrogen material (straw). However, the more narrow ratios were found with treatments of a high-nitrogen (leguminous) material. The soil to which muck was added did not show a more narrow ratio at the end of 2 years than at the beginning because the muck had undergone very little decomposition. In general, carbon was lost from these soils at a much more rapid rate than the transformation of organic to mineral nitrogen occurred and the total loss of carbon was inversely proportional to the original nitrogen content of the added organic matter. There was, however, a decided decrease in organic nitrogen in each soil (column 4, Table 2) with a corresponding increase of nitrate nitrogen.

The nitrate content of each soil at 4-month intervals is presented in Table 3. Generally speaking, the nitrate content of the soils did not increase greatly after 8 months. In some instances there were decreases after that period. Lime did not show a consistent effect on the accumulation of nitrates. When lime was used with sweet clover, the nitrate level was lower at every sampling than where it was omitted. (Compare treatments Nos. 5 and 14.) The reverse was found where alfalfa roots were added except at the end of 8 months (treatments Nos. 3 and 13). Of particular interest is the much greater accumulation of nitrates following addition of straw than of muck. In the soil to which 20 tons of muck were added with 20 tons of straw the accumulation of nitrates was only slightly greater than in the case where 20 tons of straw were used alone. There were more nitrates in the "check" soil at the last two sampling dates than in the soil to which muck alone was added. The lower nitrate content where straw was added with leguminous materials indicates a nitrate tie-up. The nitrates accumulated at a slower rate where the straw was added with the legume. (Compare treatments Nos. 3 and 8 and 5 and 12.) A more pronounced effect no doubt would have been obtained had samples been taken at an earlier period. Ammonium sulfate added with straw increased nitrate accumulation but calcium cyanamide did not.

The amount of organic matter accumulating in any particular soil was greatly influenced by the nitrogen content of the organic material added. In general, those materials with the higher nitrogen content resulted in a greater organic matter accumulation accompanied by a greater release of nitrates.

TABLE 3.—*Nitrate accumulation in soils receiving organic matter, nitrogen fertilizer, and lime treatments.*

Soil treatment*		Milligrams of nitrate nitrogen per 100 grams of oven-dry soil†					
No.	Materials and amounts	4 months	8 months	12 months	16 months	20 months	24 months
1	No treatment	2.2	7.6	4.4	3.8	7.2	6.8
2	20 tons straw	4.2	6.0	7.0	9.6	11.8	9.8
3	20 tons alfalfa roots	13.6	23.4	21.8	21.0	19.2	18.6
4	20 tons muck	6.4	7.6	6.8	4.6	4.8	5.6
5	20 tons sweet clover plants	15.4	23.4	22.0	24.6	28.2	25.4
6	20 tons straw + 500 lbs. $(NH_4)_2SO_4$	6.0	8.8	9.8	13.0	13.0	11.2
7	20 tons straw + 500 lbs. $CaCN_2$	2.2	6.4	7.8	7.0	10.6	8.2
8	20 tons straw + 20 tons alfalfa roots	10.6	18.0	19.6	23.2	26.2	21.6
9	10 tons straw + 10 tons alfalfa roots	7.2	11.8	16.8	16.6	12.0	12.4
10	20 tons straw + 20 tons muck	3.0	6.0	8.2	10.6	12.0	12.4
11	10 tons straw + 10 tons muck	3.6	7.2	7.6	9.2	11.2	10.4
12	20 tons straw + 20 tons sweet clover tops	13.2	19.8	25.2	28.6	32.4	28.2
13	20 tons alfalfa roots + 3 tons lime	18.4	22.0	23.8	26.8	28.2	25.4
14	20 tons sweet clover plants + 3 tons lime	14.8	19.8	18.2	17.8	17.4	15.8
15	20 tons straw + 20 tons alfalfa roots + 3 tons lime	11.8	16.8	20.6	17.2	19.0	18.4
16	10 tons straw + 10 tons alfalfa roots + 3 tons lime	8.8	13.8	15.4	16.2	19.6	18.4
17	20 tons alfalfa plants + 3 tons lime	18.0	25.2	24.2	26.8	29.2	31.6

*Treatments represent rates per acre.
†The soil used contained 3.0 mgms of nitrate nitrogen per 100 grams oven-dry soil

The importance of organic matter in the soil is not limited to its chemical and biological effects for it also exerts important physical effects. Its effect on the water-retaining capacity of some soils may be its greatest attribute. Moisture data in relation to the amount and kind of soil organic matter in the soils under investigation are shown in Table 4. At the end of 24 months the "no treatment" soil had a moisture-holding capacity of 27.1%, a moisture equivalent of 12.2%, and 0.71% hygroscopic water. The corresponding values for the treated soils relative to the "check" are shown in Table 4 (columns 2, 3, and 4).

In columns 7 and 8 of Table 4 are shown calculated values for the amount of water retained per gram of accumulated organic matter. In arriving at these values combustible loss was taken as organic matter. This is justified since the value for combustible loss for the check was subtracted from each treated soil. Likewise, the value for moisture retained in untreated soil was deducted from values obtained for treated soils. It is of particular interest to note the relatively large amount (2.6 to 19.3 grams) of water retained by the soil per gram of accumulated organic matter (accumulated from that which was added).

The data presented in Table 4 show that organic matter markedly affects the water-holding capacity of the soil. It is assumed that such differences in water retention mean corresponding increases in available water for plant utilization. This assumption is perhaps correct providing the added organic matter does not enhance evaporation. In order to determine the effect of organic matter on the loss of water due to evaporation, the following simple experiment was performed. Water equivalent to the maximum water-holding capacity of each soil was added to a series of Erlenmeyer flasks (125 cc capacity) and 100 grams of soil added to its proper flask. The soil was introduced slowly through a funnel after which the contents of the flasks were slightly tamped to eliminate air pockets. The flasks were left open in the laboratory and weighed at intervals varying from 1 to 7 days to determine loss of water by evaporation. The absolute amount of water lost by evaporation from determination to determination was about the same in all cases. Evaporation per 24 hours was no greater during the first few days. There was no indication that, in those flasks to which organic matter was added, evaporation losses increased even though the water content was greater. Evaporation was allowed to continue for 50 days and there was no apparent decrease in relative rate of loss for the different treatments during that period. The samples were then placed in an oven at 110° C for a period of 24 hours. The percentage of added water that was retained by each soil at the end of 50 days is shown in column 9 of Table 4. The check soil lost a much greater proportion of the added water than did the treated soils. If the above-mentioned soil organic matter-moisture relationships hold under field conditions their practical significance is obvious.

In order to determine the relationship existing between certain moisture values and organic matter, and between total carbon and organic matter of these soils, correlation coefficients were calculated.

TABLE 4.—*Moisture-retaining power of soils as affected by organic matter.*

Soil treatment*		Water-holding capacity†	Moisture equivalent‡	Hygroscopic moisture§	Total carbon as % of check	Combustible loss as % of check	Grams H_2O held per gram of organic matter‖		Per cent of added water retained after 50 days
No.	Materials and amounts						Hilgard cup method	Moisture equivalent	
1	No treatment.	100	100	100	100	100	—	—	39.6
2	20 tons straw	111	117	105	117	113	10.0	7.0	50.2
3	20 tons alfalfa roots	110	118	112	125	121	5.6	4.6	51.5
4	20 tons muck	116	120	150	180	152	2.6	2.0	53.9
5	20 tons sweet clover plants	120	122	114	122	117	13.5	6.9	50.3
6	20 tons straw + 500 lbs. $(NH_4)_2SO_4$	116	119	110	118	115	12.2	6.5	49.3
7	20 tons straw + 500 lbs. $CaCN_2$	115	122	104	119	114	12.4	8.1	50.2
8	20 tons straw + 20 tons alfalfa roots	136	141	121	136	135	11.9	6.0	54.8
9	10 tons straw + 10 tons alfalfa roots	109	123	107	119	113	6.7	9.0	49.7
10	20 tons straw + 20 tons muck	137	155	155	192	170	6.0	4.0	52.7
11	10 tons straw + 10 tons muck	111	129	127	149	138	3.2	3.8	53.3
12	20 tons straw + 20 tons sweet clover tops	151	152	124	142	138	15.6	7.0	55.8
13	20 tons alfalfa roots + 3 tons lime	125	132	116	125	118	15.9	9.2	51.1
14	20 tons sweet lcover plants + 3 tons lime	118	139	113	121	114	15.1	14.2	50.7
15	20 tons straw + 20 tons alfalfa roots + 3 tons lime	152	155	126	141	131	19.3	9.1	58.9
16	10 tons straw + 10 tons alfalfa roots + 3 tons lime	127	120	112	120	117	18.2	6.2	53.2
17	20 tons alfalfa roots + 3 tons lime	121	127	115	121	121	11.2	6.6	54.8

*Treatments represent rates per acre.
†Hilgard cup method.
‡Bouyoucos method.
§Air-dried soils placed in oven at 110° C for 12 hours.
‖Data for combustible loss were used and values for check were subtracted from treated soils (24 months).

These data are shown in Table 5 and are presented graphically in Figs. 1 and 2. In making these calculations the soils to which muck was added were omitted.

TABLE 5.—*Interrelationships of carbon, organic matter, and certain moisture values.*

Factors correlated	Correlation coefficient	Number of comparisons
Total carbon and combustible loss	.964* ± .0196†	14
Water-holding capacity and combustible loss	.883 ± .0611	14
Increase in water-holding capacity and increase in organic matter	.863 ± 0737	13
Water-holding capacity and hygroscopic water	.919 ± .0431	14
Water-holding capacity and moisture equivalent	.900 ± .0527	14
Moisture equivalent and hygroscopic water	.872 ± .0665	14

*Corrected for small number of cases.
†Standard error.

It is obvious from an inspection of the data given in Table 5 that a very close relationship exists in this particular soil, variously treated, between total carbon and combustible loss and between water-holding capacity and combustible loss. When these factors are correlated, correlation coefficients are obtained that are highly significant statistically. A correlation coefficient of .863±.0737 is obtained when increase in water-holding capacity is correlated with increase in organic matter. It is of interest to note the high degree of correlation existing between the three forms (or moisture values) of soil water for this particular soil. For example, a correlation coefficient of .900±.0527 is obtained by correlating water-holding capacity and moisture equivalent, a similar correlation coefficient for water-holding capacity and hygroscopic water, and also for moisture equivalent and hygroscopic water. Since moisture determinations by either of the above-mentioned methods are arbitrary and only relative at best, it would seem from the results here reported that the three moisture determinations yield results of about equal value In other words, just as good an idea of a soil's ability to hold water can be obtained with the Hilgard cup as with the moisture equivalent method or the determination of hygroscopic water. It is not to be inferred that the relationships indicated for this soil will necessarily hold for soils in general.

DISCUSSION AND SUMMARY

Several investigations show that the nitrogen content of a soil tends to come to equilibrium at a point that depends upon the effective climate and the cropping system as it effects organic matter additions. Soils in their natural state, where there is sufficient rainfall, are covered with a mat of decomposing grass or leaves. Cultivation dis-

turbs this condition and increases the rate of decay of the organic matter.

In general farming practices it is logical to place more emphasis on the activity of the organic matter rather than to attempt to raise it to a high level by the use of organic manures and fertilizers. Certain intensive crops, however, may demand a uniform water supply which

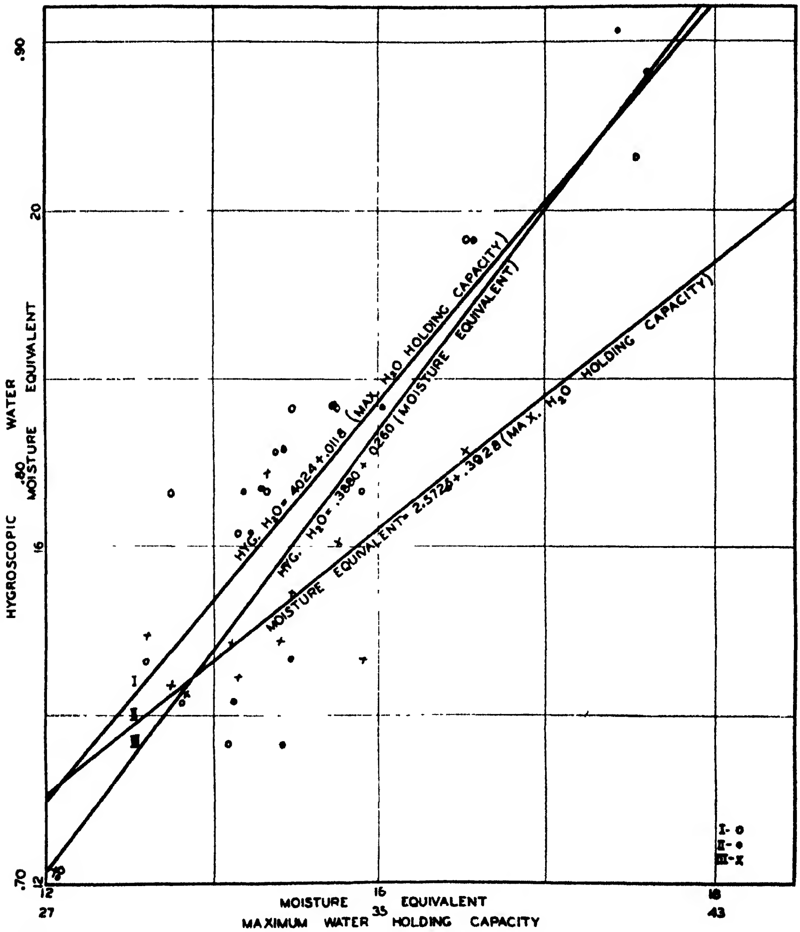

FIG. 1.—Interrelationship of certain moisture values (hygroscopic water, moisture equivalent, and maximum water-holding capacity) in soil containing different amounts of organic matter.

a high organic matter level helps to maintain. Under these conditions building up the soil organic matter above its natural level may be profitable.

The results of the investigations here reported show that materials with a wide carbon-nitrogen ratio lost a larger percentage of their carbon than those with a narrower ratio. A loss of 69% or more of the

added organic matter occurred in 2 years in every soil except that to which muck was added. Most of this loss occurred during the first 4

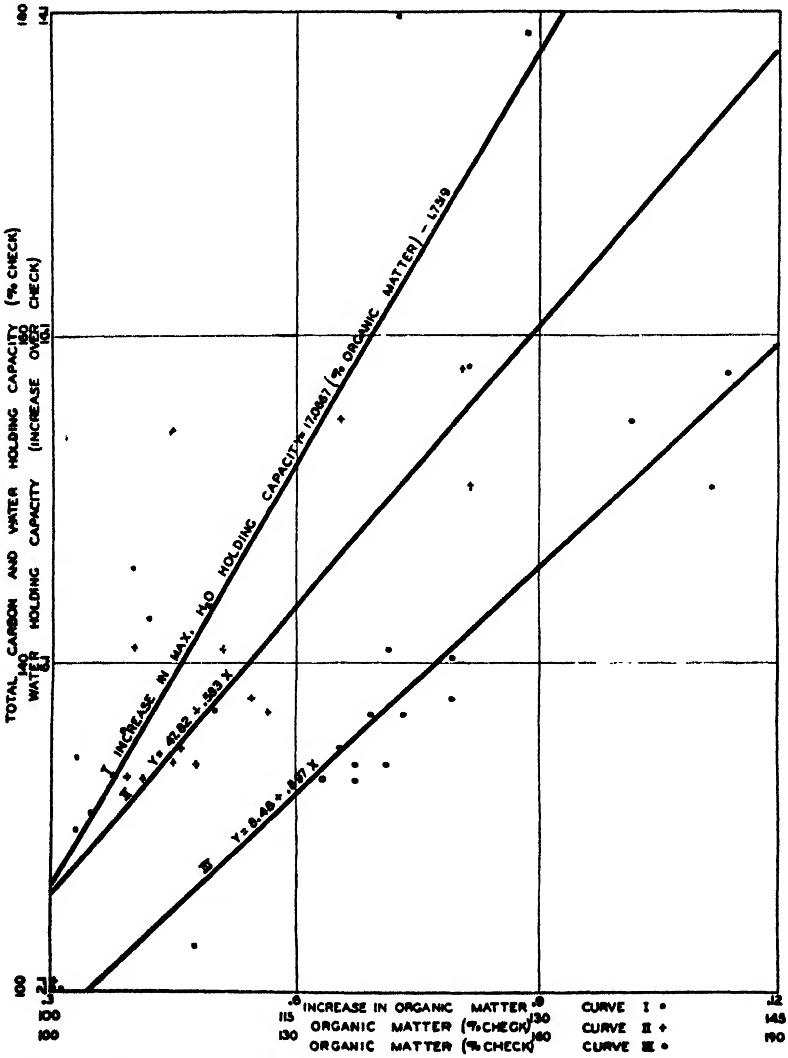

FIG. 2.—Relationship between increase in maximum water-holding capacity and increase in organic matter (curve I), water-holding capacity and total organic matter (curve II, values expressed relative to "check"), and carbon and total organic matter (curve III, values expressed relative to "check").

months of the study. Since the experiment was set up in the greenhouse, decomposition proceeded faster than it does under most field conditions due to the higher temperature, but the same relative differences in the variously treated soils would probably be obtained in

the field. Only 25% of the carbon and 18% of the organic matter added in the form of straw applied at the rate of 20 tons of dry material per acre remained in the soil at the end of 2 years. Had the soil been growing a crop which would have utilized some of the nitrogen the results doubtless would have been lower. This shows the futility of attempting to build up soil organic matter by turning under straw or other low-nitrogen materials.

The addition of $(NH_4)_2SO_4$ to straw resulted in the accumulation of more organic matter, although the increase was not great. Theoretically, the quantity of nitrogen fertilizers applied in this experiment will not give large differences in the resulting organic matter, because only the equivalent of a 500-pound per acre application of $(NH_4)_2SO_4$ was used. One gram of $(NH_4)_2SO_4$ contains 0.2 gram of nitrogen. This quantity of nitrogen could fix only about 2.4 grams of carbon, assuming a carbon-nitrogen ratio of 12:1. If this quantity were so fixed, it would increase the carbon content of the soil only 0.06%. Since 81.5 grams of straw with a nitrogen content of 0.75% was added to 4,000 grams of soil, only 0.61 gram of nitrogen was added. This quantity of nitrogen could theoretically fix 7.33 grams of carbon. Therefore, 9.73 grams (7.33 plus 2.4) is the total quantity of carbon that could be fixed by both the nitrogen of the $(NH_4)_2SO_4$ and the nitrogen of the straw. This quantity of carbon (9.73 grams) should give an increase in the soil of 0.243% carbon, assuming all the nitrogen is active in holding carbon. The actual difference in carbon between this and the check soil as found by analysis, was 0.18%, which is not far from the theoretical value. It is interesting to note in this connection that there was more nitrate nitrogen in the treated than in the untreated soil (Table 3), which, of course, was not holding carbon.

Thirty-five per cent of the added carbon in the alfalfa plants and 34% in the sweet clover plants remained in the soil at the end of 2 years, whereas only 25% of that of the straw was present at that time. This shows that the nitrogenous materials are of much greater value for increasing the organic matter of the soil than, are carbonaceous materials and that at the same time they release more nitrogen for plant use.

The carbon-nitrogen ratio of each soil became more narrow except in the untreated soil and in the one to which muck was added alone. The ratios were narrowed to or below that of the check in every instance except where muck was used. Since muck is largely plant material in an advanced stage of decomposition, its ratio of carbon to nitrogen did not change much during a 2-year period after being added to a mineral soil. Those soil treatments having the more narrow carbon-nitrogen ratios at the beginning of the experiment did not possess the more narrow ratios at the end. It is the opinion of the writers that the carbon-nitrogen ratios would have become more narrow if the nitrates had been removed as occurs under field conditions.

Large quantities of nitrates accumulated with all treatments. The greatest accumulation of nitrates occurred with the additions of leguminous materials, while the smallest accumulations followed

additions of muck and straw. The low quantity of nitrates present in the muck-treated soil at the end of the experiment is in agreement with its slow rate of loss of carbon or its slow decomposition.

In most cases lime did not show any consistent effect on the quantity of nitrates accumulated (original soil had a pH of 5.5). Straw added with leguminous materials delayed the accumulation of nitrate nitrogen and under field conditions this would decrease leaching losses of nitrate nitrogen. The results show that under conditions where organic matter of a wide carbon-nitrogen ratio is plowed under, as for example straw, a treatment with a nitrogen fertilizer will overcome the depressing influence on nitrate accumulation and will also tend to retain more of the organic matter or carbon in the soil.

In most cases lime increased organic matter decomposition, as would be expected in an acid soil. Under field conditions, the increased crop residue obtained with the use of lime will off-set the increase in the rate of decomposition of the soil organic matter occasioned by the lime.

A high correlation coefficient was found when differences (increases over check) in soil organic matter were correlated with differences (increases over check) in water-holding capacity.

Since soil miosture is, in general, the greatest limiting factor in the production of potatoes, and of many fruit and truck crops, on the sandy soils of Michigan, it would seem logical and economical from the results reported herein to add large quantities of organic material to these soils for the main purpose of increasing their water retentiveness. The leguminous or more nitrogenous materials are most effective for this purpose, while straw and similar carbonaceous material supplemented with liberal applications of commercial nitrogen may also be used.

NOTES

INHERITANCE OF SEEDLING STEM COLOR IN A BROOMCORN-SORGHUM CROSS

INHERITANCE of seedling stem color in a number of crosses between different types of grain sorghums was worked out and reported by Reed.[1] Certain grain sorghums, as Red Amber Sorgo, Sumac Sorgo, Durra, and Milo, had red seedlings, and in certain others, as Dawn, Kafir, Feterita, Shallu, and Black Amber Sorgo, the seedlings were green. In inheritance, red was dominant to green and in F_2 a ratio of 3 red to 1 green was obtained.

During the course of certain preliminary studies on broomcorn at the Illinois Agricultural Experiment Station, a planting was made of the F_2 generation of a cross between Shallu, a grain sorghum, and Black Spanish broomcorn. The seed was kindly furnished by Dr. John Martin, Sorghum Investigations, Bureau of Plant Industry, U. S. Dept of Agriculture, the cross having been made by him and the F_1 generation grown at Arlington Farm.

When the F_2 seedlings were 2 or 3 inches tall, it was observed that they were segregating for stem color. Counts were made in one row before any thinning was done. Of a total of 336 seedlings, 194 had red stems and 142 had green stems. This at once suggested a 9:7 ratio of red to green On the basis of this ratio, the expected numbers would be 189 red to 147 green, a deviation of 5 from expectation.

At thinning, all the green-stemmed seedlings were removed from the row on which the above counts were made, leaving only the red-stemmed to develop In the fall the heads were harvested from each F_2 plant in this row, hung up to dry, threshed, and a portion of the seed of each planted in a sand bench in the greenhouse for counts on stem color. The results are given in Table 1.

On the assumption of two genes, both of which must be present to produce red, there should be three types of F_2 red-stemmed plants on the basis of breeding behavior. These types are as follows: (1) Breed true for red, (2) segregate for red and green in a 3:1 ratio, and (3) segregate for red and green in a 9:7 ratio; and these types should occur in the ratio of 1:4:4.

That these expectations were realized, in the main, is evident from a study of the data in Table 1. All three types were obtained and in approximately the expected ratio. Of 126 plants tested, 13 bred true for red, 70 segregated in a 3:1 ratio, and 43 segregated in a 9:7 ratio, the expected numbers on the basis of a 1:4:4 ratio being 14, 56, and 56, respectively. When the X^2 goodness of fit was applied, X^2 was found to be 7.52 and the probability, P, was .024. Hence, on the basis of random sampling, a worse result might be expected 24 times in 1,000 trials or once in 42 trials.

Some difficulty was experienced with a few F_3 families in determining whether the segregation ratio was 3:1 or 9:7, and there may be a few errors on that account. However, in all doubtful cases, the prob-

[1]REED, GEORGE M. A new method of production and detecting sorghum hybrids. Jour. Heredity, 21:133–144. 1930.

TABLE 1.—*Breeding behavior in F_3 of red-stemmed F_2 plants of a broomcorn-sorghum hybrid with respect to seedling stem color.*

Plant	Red	Green	Total	Type of segregation	Plant	Red	Green	Total	Type of segregation
1	32	12	44	3:1	47	107	31	138	3:1
2	44	23	67	9:7	48	40	22	62	9:7
3	98	35	133	3:1	49	53	28	81	9:7
4	35	22	57	9:7	50	71	37	108	9:7
5	113	39	152	3:1	51	42	6	48	3:1
6	54	45	99	9:7	52	23	15	38	9:7
7	43	16	59	3:1	53	33	17	50	9:7
8	80	30	110	3:1	54	55	22	77	3:1
9	103	31	134	3:1	55	23	9	32	3:1
10	129	46	175	3:1	56	18	18	36	9:7
11	72	54	126	9:7	57	43	25	68	9:7
12	69	5	74	3:1	58	39	18	57	3:1
13	55	9	64	3:1	59	48	19	67	3:1
14	115	39	154	3:1	60	146	28	174	3:1
15	66	18	84	3:1	61	70	34	104	3:1
16	54	30	84	9:7	62	72	35	107	3:1
17	39	21	60	9:7	63	9	0	—	Bred true
18	95	42	137	3:1	64	59	19	78	3:1
19	148	102	250	9:7	65	82	18	100	3:1
20	164	41	205	3:1	66	87	29	116	3:1
21	118	29	147	3:1	67	49	28	77	9:7
23	129	37	166	3:1	68	20	6	26	3:1
24	82	24	106	3:1	69	34	14	48	3:1
25	132	50	182	3:1	70	67	21	88	3:1
26	115	39	154	3:1	71	182	166	348	9:7
27	94	39	133	3:1	72	81	33	114	3:1
28	104	39	143	3:1	73	86	37	123	3:1
29	139	43	182	3:1	74	90	22	112	3:1
30	65	40	105	9:7	75	43	16	59	3:1
31	70	56	126	9:7	76	72	39	111	9:7
32	110	25	135	3:1	77	68	8	76	3:1
33	116	48	164	3:1	78	57	21	78	3:1
34	38	27	65	9:7	80	81	43	134	3:1
35	105	50	155	9:7	81	40	37	77	9:7
36	120	0	—	Bred true	82	92	0	—	Bred true
37	95	36	131	3:1	83	55	31	86	9:7
38	75	58	133	9:7	84	29	7	36	3:1
39	181	0	—	Bred true	85	53	27	80	3:1
40	155	0	—	Bred true	86	87	46	133	9:7
41	77	23	100	3:1	87	56	13	69	3:1
42	97	35	132	3:1	88	—	—	—	—
43	96	31	127	3:1	89	73	1	—	Bred true
44	33	5	38	3:1	90	—	—	—	—
45	42	21	63	3:1	91	31	0	—	Bred true
46	146	61	207	3:1	92	72	0	—	Bred true

TABLE 1.—*Continued.*

Plant	Red	Green	Total	Type of segregation	Plant	Red	Green	Total	Type of segregation
93	24	13	37	9:7	114	37	26	63	9:7
94	33	18	51	9:7	115	61	41	102	9:7
95	9	6	15	9:7	116	9	4	13	9:7
96	117	28	145	3:1	117	45	1	—	Bred true
97	109	39	148	3:1	118	11	7	18	9:7
98	120	22	142	3:1	119	21	6	27	3:1
99	7	6	13	9:7	120	43	8	51	3:1
100	131	19	150	3:1	121	115	19	134	3:1
101	—	—	—	—	122	20	14	34	9:7
102	23	13	36	9:7	123	50	22	72	3:1
103	65	62	127	9:7	124	91	21	112	3:1
104	44	0	—	Bred true	125	32	27	59	9:7
105	52	18	70	3:1	126	55	23	78	3:1
106	19	0	—	Bred true	127	41	37	78	9:7
107	53	0	—	Bred true	128	95	34	129	3:1
108	37	6	43	3:1	129	114	60	174	9:7
109	18	0	—	Bred true	130	12	12	24	9:7
110	34	21	55	9:7	131	49	19	68	3:1
112	14	13	27	9:7	132	137	90	227	9:7
113	54	5	59	3:1					

able error was calculated and divided into the deviation from the expected ratio. The size of the quotient thus obtained was used as the determining factor, the ratio with the smaller quotient being chosen to apply to the particular segregating family under consideration.—C. M. WOODWORTH, *Plant Breeding Division, Agronomy Department, Illinois Agricultural Experiment Station, Urbana, Ill.*

THE TERM "RANGE WEED" AS USED BY WESTERN STOCKMEN AND THE U. S. FOREST SERVICE

REFERENCE is made to Dr. Pieters' excellent essay of inquiry, "What is a Weed?" which opens the October, 1935, issue of this JOURNAL. Because of Dr. Pieters' criticism of U. S. Forest Service usage of the term "weed", apparently based, in part, on definitions in my *Glossary of Botanical Terms used in Range Research* (U. S. D. A. Misc. Pub. 110, 1931), and his recommendation that we adopt the term "forb", may I be permitted an opportunity to present certain facts and viewpoints, in order that readers of the JOURNAL may get the full background involved?

Any fair-minded person must admit that Dr. Pieters' theses have much merit and strong arguments to support them, and that it is unfortunate that any word in common usage should have ambiguity resultant from differences in interpretation by diverse groups. I submit, however, that, from the standpoints of historicity and usage, to the Forest Service is not traceable the paternity of the word "weed" *in sensu nomologico*. In the first place, while Dr. Pieters' definition

and comments on the English word "weed" well harmonize with definition "1" of the word in the New English (Oxford) Dictionary—probably the most scholarly and authoritative lexicon of our language extant—yet it also as clearly does not apply to "weed" definitions "b", "c", "e", and "2" of that work. In the second place, numerous, long-established English plant names with "-weed" as a suffix, *e.g.*, bugleweed, ironweed, Joe-pye-weed, pickerelweed, snapweed, and willowweed, exist wherein the "-weed" portion of the name does not at all connote essential undesirability. In the third place (perhaps unfortunately, it is true), "weed" is universally used by western stockmen for nongrasslike herbs. In other words, the Forest Service has had a strong, uniform intrenched field usage to deal with from the start.

It is true that some Forest Service technical men in scientific papers of an ecological nature, have used Dr. Clements' term "forb". Laying aside any question as to form, "forb" is admittedly an Anglicization or free transliteration of the Greek word φορβή, food—especially forage or fodder. Frankly, I gravely doubt if "forb" will ever be adopted by the horny-handed stockman and cowpuncher. He will say to us: "Talk 'United States'"! Furthermore, it seems to me that, from its basic etymology, "forb" cannot properly be a thorough synonym of the range "weed". The stockman's "weed" covers nongrasslike herbs whether palatable, nonpalatable, poisonous, harmless, injurious, desirable, or undesirable—it is a true vegetative *type*. "Forb", irrespective of whether it might not also rightfully include grass, sedges, rushes, and browse, at least in essence connotes palatable, harmless, and desirable species only.

It is Forest Service practice, in publications employing the word "weed" *in the range sense*, to give a definition of the term so that there can be no conflict with the agronomic or agricultural use of the word, and to use the phrase "range weed" as much as possible, so that the reader will be in no doubt as to what is meant. It is, of course, a very fair question whether some other term would not be preferable. Dr. Sampson in his text, *American Native Forage Plants*, invented the phrase "broad-leaved herbs", but that is awkward and often inaccurate and misleading. "Nongrasslike herbs" is also awkward, and too long. Until some bright mind suggests a term on which stockman, range administrator, scientist, farmer, and agronomist will unite, it is my personal feeling that the Forest Service is justified in retaining the phrase "range weed" for its nongrass, nongrasslike, herbaceous range vegetation.—W. A. DAYTON, *Senior Forest Ecologist, in charge, Range Forage Investigations, Division of Range Research, U. S. Forest Service, Washington, D. C.*

AN INTERESTING SEED COMBINATION

EARLY in 1935, the junior writer obtained a commercial sample of oats in which many of the primary grains appeared to have a seed of another plant growing within them. On careful examination it was found that seeds of the Napa thistle (*Centaúrea melitênsis* L.) were lodged on the palea behind the folds of the lemma, thus giving the interesting double seed combination shown in Fig. 1. The thistle seeds probably were deposited at an early stage in the development of the oat lemmas and caryopses. In fact, the thistle seed appeared to have caused depressions in the oat kernels at the points of contact. It is not believed that they could have been deposited so well at later stages in the development of the grain or in the harvesting and threshing operations.

FIG. 1.—Upper row, normal oats; middle row, oat grains with Napa thistle seeds deposited within them; lower row, thistle seeds removed from the oat grains.

These oats had been grown in western Oregon where the Napa thistle is a noxious weed. This variety of thistle matures quite early and may have been shedding its seeds at about the time these oats were flowering. The large pappus of the thistle seeds greatly favor their dissemination by wind. It is said that at time of ripening if the wind happens to be blowing the atmosphere becomes filled with these seeds and that they are carried long distances. In the case of these oats it is possible that a strong wind blew for a few days just at the opportune time, or otherwise the thistle seeds would not have been deposited so precisely within the oat lemmas.

A seed combination of this kind is new to the writers, who have observed and worked with oats from various regions of the United States for many years. Quack and similar seeds, however, are frequently found embedded in grains of commercial oats.

It is not advisable to use for seed any oats that have Napa thistle, quack, or other noxious weed seeds embedded in the grains, as the weed seeds lodged behind the folds of the oat lemma cannot be removed by mechanical means and would, therefore, be planted with

the oats.—T. R. STANTON and E. G. BOERNER, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, and the Grain Division, Bureau of Agricultural Economics, U. S. Dept. of Agriculture.*

LONGEVITY AND VIABILITY OF SORGHUM SEED

RESULTS upon the viability of old sorghum seed were published in the May 1928 number of this JOURNAL. In the course of breeding work with sorghums, seed from numerous selections and hybrids accumulate and the question of how long such remnant seed might be useful and retain its power of germination is an important one. Also, the expectancy, or longevity, before germinability is completely exhausted is of interest as prior to that time even a very low percentage of germination might suffice to recover and renew the stock.

In breeding work with sorghums at the Lubbock, Texas, Substation, seed stock from original selections made in 1917 was preserved. Seed of Blackhul kafir, stored in the laboratory in ordinary seed envelopes and protected from weevil, have been tested for germination at intervals of 1 or 2 years since 1924. Results of these tests were as follows:

Year	%	Year	%
1917	(100)	1931	34.2
1924	88.0	1933	15.5
1926	79.5	1935	4.0
1927	65.0	1936	0.5
1929	48.0		

Theoretically, the viability of this sorghum seed when harvested in 1917 was 100% and, with this assumption, it lost only 12% of its viability in the first 7 years. After 10 years almost half of the seed still retained power of germination, but thereafter it lost its viability quite rapidly until in the nineteenth year only 1 seed grew out of 200 tested. A duplicate test of 200 seeds was made on sterilized agar in 1936 and two seeds succeeded in sending out very weak sprouts. After 1931, it was noted that in each of the tests even the seed that responded with growth in many cases showed only weak germination and lacked the vigorous sprouts commonly found in fresh seed.

Ayyangar and Ayyar, of the Agricultural Research Institute, Coimbatore, India, recently reported that sorghum seed there, when preserved in the head, showed a viability of around 90% for 3 or 4 years, but that in no case did 7-year-old seed germinate. Threshed seed stored in bottles deteriorated to a germination of only 10% after 4 years. Moisture, humidity, and temperature conditions in storage undoubtedly are the important factors affecting the rate of deterioration, and the fact that the seed stored at Lubbock were in a relatively dry region where the humidity is low and high temperatures of short and infrequent occurrence is likely responsible for the slow rate of deterioration.

The graph in Fig. 1 quite clearly illustrates the decline in viability as well as the longevity, or life-span, or sorghum seeds stored under conditions favorable to their retention of germinating powers. It is

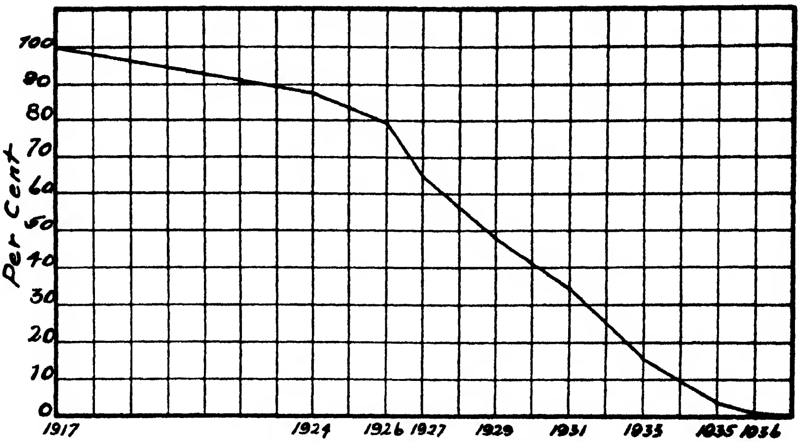

FIG. 1.—Curve showing the decline in the viability of sorghum seed over a 19-year period.

apparent that a smooth curve fitted to these results would closely approach in form the right one-half of a normal frequency curve and may be considered as a "death curve". If the growth curve of a sorghum plant is considered as the other half, and if the two are reduced to relative terms, the complete normal curve will be approached; however, the cycle involved in the growth is 3 to 4 months, whereas that of decline, or death, is approximately 20 years.—R. E. KARPER and D. L. JONES, *Texas Agricultural Experiment Station, College Station, Texas.*

AGRONOMIC AFFAIRS

MEETING OF THE NORTHEASTERN SECTION

THE annual meeting of the Northeastern Section of the Society will be held at the West Virginia Agricultural Experiment Station, Morgantown, W. Va., June 24 to 26. Details of the program will appear in the next issue of the JOURNAL. Professor J. S. Owens, Connecticut Agricultural Experiment Station, Storrs, Conn., is Secretary-Treasurer of the Northeastern Section.

TENTATIVE PROGRAM FOR MEETING OF AMERICAN SOIL SURVEY ASSOCIATION AND SOILS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

A TENTATIVE program for the 1936 annual meeting of the American Soil Survey Association and of the Soils Section of the American Society of Agronomy to be held in Washington, D. C., is submitted at this early date for its suggestive value. It has not been possible for the various chairmen to announce all the subjects for discussion or to present extensive plans, so these must come at a later date. This program is subject to revision. Other sectional programs may be added and necessary changes may be made in those given. The program is submitted as a general plan for consideration. The various chairmen solicit cooperation with suggested subjects and by means of early announcements regarding contributions to the program.—GEORGE D. SCARSETH, *President, American Soil Survey Association;* and WM. A. ALBRECHT, *Chairman, Soils Section, American Society of Agronomy.*

TUESDAY MORNING

8:00– 9:00 Registration American Soil Survey Association

9:00– 9:15 General Assembly, Announcements, Appointment of Committees

SECTION V.—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

9:15–10:30 Committee on Soil Survey Maps, Reports and Technic of Mapping —T. M. Bushnell, Purdue University, Lafayette, Ind., *Chairman*

10:30–11:30 Committee on Organic and Water Soils—J. O. Veatch, Michigan State College, East Lansing, Mich., *Chairman*

11:30–12:00 Committee on Exchange of Profiles—H. J. Harper, Oklahoma Agricultural College, Stillwater, Okla., *Chairman*

TUESDAY AFTERNOON

SECTION V.—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

Session A

1:30– 4:00 Committee on Forest Soils—J. T. Auten, Central States Forest Exp. Sta., Columbus, Ohio, *Chairman*

Session B

1:30– 2:30 Committee on Soil Structure—L. D. Baver, University of Missouri, Columbia, Mo., *Chairman*

2:30– 3:15 Committee on Horizon Criteria—E. A. Norton, Soil Conservation Service, Des Moines, Iowa, *Chairman*

3:15– 4:00 Committee on Nomenclature—G. E. Conrey, Ohio Experiment Station, Wooster, Ohio, *Chairman*

4:00– 5:00 Business Meeting American Soil Survey Association—G. W. Scarseth, *Chairman*

Report of the Committee for Drafting a Constitution for the American Society of Soil Science

7:00 P. M. Dinner American Soil Survey Association

WEDNESDAY MORNING

Registration American Society of Agronomy

SECTION I.—SOIL PHYSICS

Submitted and solicited papers—L. D. Baver, University of Missouri, Columbia, Mo., *Chairman*

SECTION IV.—SOIL FERTILITY

Submitted and solicited papers—F. C. Bauer, University of Illinois, Urbana, Ill., *Chairman*

SECTIONS V AND VI.—SOIL MORPHOLOGY AND SOIL SCIENCE APPLIED TO LAND USE

G. D. Scarseth, Alabama Polytechnic Institute, and R. V. Allison, Soil Conservation Service, Washington, D. C., *Co-chairmen*

Committee on Soil Geography—Mark Baldwin, Bureau of Chemistry and Soils, U. S. Dept. Agr., Washington, D. C., *Chairman*

Submitted and solicited papers

Land Classification and Land Use

Submitted and solicited papers

WEDNESDAY AFTERNOON

SECTION II.—SOIL CHEMISTRY

R. H. Bray, University of Illinois, Urbana, Ill., *Chairman*

Committee on Processes and Products of Soil Weathering—M. S. Anderson, Bureau of Chemistry and Soils, U. S. Dept. Agr., Washington, D. C., *Chairman*

Submitted and solicited papers

Symposium: What Constitutes Availability of the Essential Elements in the Soil?

Submitted and solicited papers

SECTION IV.—SOIL FERTILITY

F. C. Bauer, University of Illinois, Urbana, Ill., *Chairman*

Submitted and solicited papers

SECTION VI.—SOIL SCIENCE APPLIED TO LAND USE

R. V. Allison, Soil Conservation Service, Washington, D. C., *Chairman*

Committee on Soil Conservation—J. G. Hutton, Soil Conservation Service, Huron, S. D., *Chairman*

Wednesday Evening

Special business meetings of the American Society of Soil Science and of the International Society of Soil Science

Thursday Morning

General Program American Society of Agronomy—R. M. Salter, Ohio Experiment Station, Wooster, Ohio, *Chairman*
Subjects and speakers to be announced

Thursday Noon

Luncheon Conference Legume Inoculants, Inspection, Production, and Tests

Thursday Afternoon

Program American Society of Soil Science—G. D. Scarseth and Wm. A. Albrecht, *Co-chairmen*
Soil Science as Related to Other Sciences
Subjects and speakers to be announced

Thursday Evening

Annual Dinner American Society of Agronomy
Presidential address, reports, and awards

Friday Morning

SECTION II.—SOIL CHEMISTRY

R. H. Bray, University of Illinois, Urbana, Ill., *Chairman*
Submitted and solicited papers

SECTION III.—SOIL MICROBIOLOGY

J. K. Wilson, Cornell University, Ithaca, N. Y., *Chairman*
Symposium: Interrelationships Between Plant Pathogens and Saprophites in the Soil Population
Submitted and solicited papers

SECTION IV.—SOIL FERTILITY IN JOINT SESSION WITH CROPS SECTION

M. T. Jenkins and F. C. Bauer, *Co-chairmen*
Symposium: Newer Developments in Experimental Design
Submitted and solicited papers

Friday Afternoon

SECTION III.—SOIL MICROBIOLOGY

J. K. Wilson, Cornell University, Ithaca, N. Y., *Chairman*
Submitted and solicited papers

SECTION VI.—SOIL SCIENCE APPLIED TO LAND USE

R. V. Allison, Soil Conservation Service, Washington, D. C., *Chairman*
Submitted and solicited papers

THE CROPS SECTION PROGRAM

TENTATIVE plans are being formulated for the Crops Section meetings at the annual meeting of the Society in Washington next November. It is proposed that a 3-day program be developed as follows: *Wednesday*, programs dealing with more technical subjects such as genetics and physiology of crop plants, and round-table discussions on special topics; *Thursday morning*, general program of the American Society of Agronomy; *Thursday afternoon*, programs on plant breeding, crops extension, and pasture management; *Friday*, programs on general phases of crops research, probably including a special program on southern field crops, and a joint symposium with the Soils Section on "Newer Developments in Deisgn of Field Experiments." A symposium on soybeans has been requested, and other programs may be developed if sufficient interest is expressed.

The purpose of this preliminary announcement is to indicate the intention of coordinating the crops meetings with those of the Soils Section. The more technical programs of each section are to be scheduled for the early part of the meetings, and the more general phases for the latter part. This will permit those interested in both phases of agronomy to attend general programs on either soils or crops during the last day of the meeting. Further details will be provided later.—H. B. SPRAGUE, *Chairman, Crops Section*.

NEWS ITEMS

DR. N. A. PETTINGER, Associate Agronomist of the Virginia Polytechnic Institute, died in the Roanoke Hospital, Roanoke, Virginia, on February 1, 1936. He had been confined to his bed with a heart trouble for the previous eight months. Dr. Pettinger came to Virginia after having obtained the Ph.D degree at the University of Illinois in 1927. He was in charge of soils teaching and research for the Virginia Polytechnic Institute and Virginia Agricultural Experiment Station.

DR. H. K. HAYES, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, has left for China where he will assume the following duties with the National Agricultural Research Bureau, Ministry of Industries, Shaolingwei, Nanking 10, China: (1) To advise on methods of breeding wheat, rice, cotton, sweet and Irish potatoes, and possibly tobacco; (2) to supervise a coordinated program for the whole nation in breeding these crops; (3) to advise on breeding disease-resistant varieties; and (4) to train in methods of plant breeding a selected group of Chinese field workers, most of whom have had graduate training abroad, especially in the United States. Dr. H. K. Wilson will serve as Acting Chief of Division during his absence.

J. O. CULBERTSON, Assistant Agronomist, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, has been transferred from Salt Lake City, Utah, to the University of Minnesota, St. Paul, Minn. Mr. Culbertson will continue agronomic investigations with sugar beets, taking over those phases of work formerly under the charge of Dr. F. R. Immer.

Dr. K. H. Klages, formerly of South Dakota State College, has been appointed head of the Department of Agronomy, University of Idaho, succeeding Professor H. W. Hulbert who has resigned to join an Idaho seed firm.

Dr. L. E. Kirk, Dominion Agrostologist, Ottawa, Canada, delivered the seventh series of the annual lectures given in recognition of the plant breeding achievements of Frank Azor Spragg, plant breeder at the Michigan Agricultural Experiment Station from 1906 to 1924. The lectures, sponsored by the Department of Farm Crops, Michigan State College, were given March 10 to 13 and covered the following subjects: Organization of Forage Crop Research in Canada; The Improvement of Pasture Grasses and Legumes; Pasture Research at Ottawa; The Breeding of Alfalfa; and Production and Control of Pedigreed Seed in Canada.

Dr. Charles E. Thorne, Director and Chief of the Soils Department of the Ohio Agricultural Experiment Station from 1887 to 1921 and Director Emeritus since then, died at his home at Wooster on February 29 in his ninetieth year. Dr. Thorne was active up to the last, and since his retirement from the directorship in 1921 he worked almost steadily in summarizing and interpreting the results of the long-time fertility experiments at Wooster and those of the Pennsylvania and Rothamsted Experiment Stations.

Dr. A. L. Grizzard, formerly assistant agronomist at the Virginia Agricultural Experiment Station in charge of T. V. A fertilizer investigations in Virginia, has been advanced to associate agronomist in charge of a pasture research project inaugurated under the Bankhead-Jones Act. Mr. E. M. Dunton, Jr., a graduate student in Agronomy and Agricultural Chemistry, has been appointed to fill the vacancy caused by Dr. Grizzard's promotion.

Dr. S. S Obenshain, formerly assistant agronomist at the Virginia Agricultural Experiment Station in charge of soil survey, has been advanced to associate agronomist and will have charge of the soil teaching and investigational work formerly carried by the late Dr. N. A. Pettinger.

The summer meeting of the corn belt section of the American Society of Agronomy will be held at the University of Illinois, Urbana-Champaign, Illinois, June 23, 24, 25. 1936.

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A DIRECT METHOD OF AGGREGATE ANALYSIS OF SOILS AND A STUDY OF THE PHYSICAL NATURE OF EROSION LOSSES[1]

ROBERT E. YODER[2]

SOIL aggregation is one of the most important dynamic properties of soils to be considered by the investigator dealing with soil tilth, erosion control, and other problems in soil physics. The property of aggregation in soils has received considerable attention by numerous European workers. Tiulin (14)[3] and Sokolovsky (12) have amply reviewed the investigations of the Russian workers who have long realized the practical significance of this soil characteristic. Ehrenberg (4) has presented a comprehensive review of the literature treating this subject. Baver and Rhoades (1) have actively led the work on aggregation of soils in this country for the past 3 years. Baver and his co-workers (2, 7, 9) have utilized a modified Kopecky elutriator for the determination of aggregate size distribution in soils.

CRITICISM OF ELUTRIATION METHOD OF AGGREGATE ANALYSIS

The elutriation method is beset with several inherent characteristics which render its application to aggregation studies questionable. A brief discussion of these characteristics follows.

LIMITATIONS IMPOSED BY STOKES' LAW

Particle density.—Application of Stokes' law (13) to the separation of various sized particles implies that they be of uniform density. This is reasonably true of the completely dispersed soil particles dealt with in mechanical analysis. The elutriation principle was advanced for the separation of such particles. However, soil aggregates are not of uniform density. Likewise, the density of aggregates of many soils is quite far removed from that of their completely dispersed particles (Table 1). The extreme variability of settling velocity of aggregates of uniform size caused by variations in aggregate density

[1]Contribution of the Department of Agricultural Engineering, Alabama Agricultural Experiment Station, Auburn, Ala. Published by permission of the Director. Received for publication January 20, 1936.

[2]Assistant Agricultural Engineer.

[3]Figures in parenthesis refer to "Literature Cited", p. 350.

is sufficient reason for rejecting the elutriation principle as a means of aggregate fractionation.

TABLE 1.—*Mean density of aggregate separates from several soils.*

Soil type	Aggregate separate, mm	Mean density*
Cecil clay	5–2	1.66
Dewey clay loam	5–2	1.25
Westmoreland silt loam	2–1	1.45
Frederick silt loam	2–1	1.25
Hartsells fine sandy loam	2–1	1.75

*These values were obtained from volume-weight measurements determined by filling the voids in a known weight of aggregates, in a volumetric flask under partial vacuum, with mercury.

Particle shape.—Smooth spherical-shaped aggregates are not commonly found in soils. The influence of particle shape on sedimentation velocity has been discussed by Keen (6). It suffices to state that soil aggregates present a variety of shapes; smooth surfaces are not common.

Particle size.—It has been pointed out by Keen (6) that the maximum size limit of soil particles which may be fractionated by methods based on Stokes' law is about 0.50 mm diameter. Many soils contain large quantities of water-stable aggregates greater than 0.5 mm in diameter.

Turbulence.—Stokes' law is valid only when the resistance to particle fall is due entirely to the viscosity of the medium. The elutriator is not free of turbulent flow.

SOIL-WATER RATIO

The quantity of water required to fractionate 10 grams of soil by the elutriation method is usually at least 15 liters. Pure water exerts a weak dispersing action upon the colloidal fraction of soils. Demolon and Henin (5) recommend the addition of $Ca(NO_3)_2$ to the water used for aggregate fractionation. This practice does not seem desirable in the case of soils of low base saturation. While the soil-water ratio is of least importance for highly leached soils, it is desirable (10) to reduce the ratio of soil to water to about 1:100. Ten grams of soil is a very small quantity upon which to determine aggregate distribution. The use of larger quantities of sample for aggregate distribution determinations can be unconditionally recommended.

MECHANISM OF THE SLAKING REACTION

The tendency of soils to break down from clods into smaller aggregates under the influence of moisture changes is one of the most significant dynamic properties of soils in relation to erosion control and tillage practices. Before suggesting a mechanism to account for the slaking reaction, it is appropriate to review briefly several characteristics of the process.

1. The slaking process is complete only when the lump of soil has been allowed to approach closely an air-dry condition. Aggregate analysis of several soils at various moisture contents, as determined by

the method reported in this paper, lead one to believe that the critical moisture condition in question corresponds to the "pendular" moisture stage of drying (6).

2. Lumps of air-dry soil do not slake if they are first slowly wetted by a water supply controlled by capillarity, i.e., by the technic of Sekara (11). Even though such moistened lumps become very soft, they retain their form when immersed in water.

3. Air-dry lumps of soil do not slake appreciably if the air contained in the pore spaces is removed previous to immersion in water; the lumps soften but their form is retained.

4. The slaking reaction does not occur when air-dry soils are immersed in non-polar, non-miscible liquids (xylol, toluol, etc.). Under such conditions the lumps remain firm and rigid even though capillarity causes them to become quickly saturated with the liquid.

5. Small roots, root hairs, and fungus mycelia frequently prevent soil lumps from completely slaking into their water stable aggregates. (This fact probably accounts for an appreciable portion of the decreased erosivity of soils under vegetative protection and other conditions where organic residues are abundant.)

Nature, through the integrated sum of her environmental factors acting through geological time on different parent rock materials, has produced a great variety of soil types, each of which is characterized by some sort of natural structure or aggregate distribution. When a lump of soil is allowed to air-dry, cleavage boundaries caused by differential shrinkage are developed along areas of lowest shear value, i. e., along aggregate boundaries. The aggregates are still coated with a thin film of sorbed water held by the colloidal surfaces. When water is supplied, these films thicken and wedge the aggregates apart; the lump swells and becomes soft. Now, if an air-dry lump is immersed in water, the water penetrates the lump at the highest rate along capillary passageways and cracks of larger dimensions. Since the pore space consists, for the most part, of a contiguous and rather fortuitous system of capillary passageways of varying size and shape, air is trapped in many passageways, particularly those of smaller cross-section dimensions. Next, these small capillaries begin to rob the larger openings of water since a steep gradient of capillary potential is present. This process compresses the entrapped air which finally causes a series of miniature explosions which continue until the lump is shattered into its water stable aggregates.

The aggregates thus formed are termed "water stable" since they are truly stable against the excess of water in which they are immersed. Of course, aggregation like many other physical properties of the soil must be considered as a dynamic property. If such a conception is maintained, the above hypothesis will be helpful to those dealing with soil problems directly dependent upon the dynamics of aggregation.

THE SIEVE METHOD OF AGGREGATE ANALYSIS

The method of aggregate analysis herein reported is based upon the slaking property of soils. A number of the weaknesses of the elutriator method are eliminated.

SAMPLING OF SOILS FOR AGGREGATE ANALYSIS

When one is to determine soil structure, or a soil property depending primarily upon soil structure, care must be taken in order that the structure be not destroyed That sampling method is best which disturbs the natural structure the least. The sampling tube shown in Fig. 1 has been found to be satisfactory. In designing this tube, consideration was given to arch action forces (8) and as a result the driven end of the tube is of such shape that the forces of compression are almost completely vectored away from the core sample. Consequently, compression of the sample is of such low magnitude that it cannot be detected by simple measurements. The tube is thus suited for making volume weight or apparent specific gravity measurements on the sample. Samples should be taken only when the soil content is below that of the lower plastic limit of the soil. Other usual precautions of soil sampling should be observed.

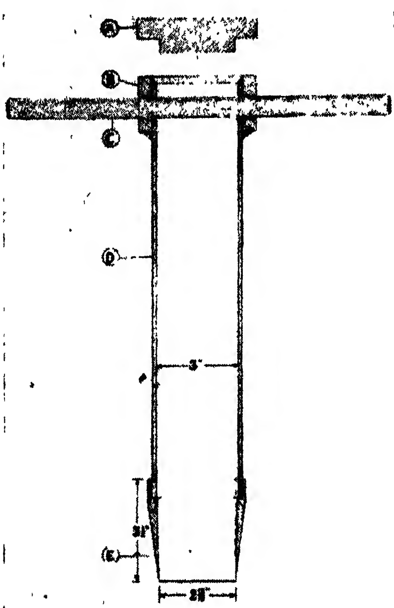

FIG. 1.—Soil sampling tube. A, steel drive cap; B, 1/2 X 2 inch shoulder strap welded to tube; C, 3/4 inch removable rod handle; D, 3/16 X 3 X 14 inch cold drawn seamless steel tube; E, removable, case-hardened steel bit.

PRETREATMENT OF SAMPLES FOR AGGREGATE ANALYSIS

Pretreatment of samples is a factor that should be standardized. Before this is done, careful investigation on the part of several independent workers would be highly desirable. (The following statements are made as a result of considerable work on the aggregation characteristics of soils of the southeastern states. These soils for the most part are acid in reaction and low in organic matter content.) It is suggested that the pretreatment consist only of allowing the sample to approach air dryness closely, immediately before making the analysis if the water stable aggregate distribution is the subject in question. To use samples at "field moisture", as recommended by Baver, simply introduces a variable factor which may lead to erroneous conclusions. Furthermore, it is pointless to determine aggregate analysis on a sample of soil which has been passed through a 2-mm screen as recommended by the above-mentioned worker. Attention is called ot data presented in Table 2. Many soils contain a considerable quantity of water stable aggregates greater than 2 mm in diameter. This pretreatment simply destroys in part that which one is attempting to measure Shaking in water is also a questionable practice. Such practice is essentially an abrasive treatment, and while it may be admirably suited for studying the mechanical stability of aggregates, it should not be used as a part of an aggregate fractionation process.

TABLE 2.—*Influence of various drying pretreatments on aggregate analysis of Cecil clay.**

Aggregate size class in mm	Percentage of total with drying pretreatment of†			
	None	Oven-dry, 110° C	96% H_2SO_4	Air-dry, 30° C
>2	48.6	66.2	14.3	20.4
2–1	22.4	17.3	24.0	23.1
1–0.5	16.7	10.4	31.0	26.8
0.5–0.25	5.9	3.1	14.8	14.9
0.25–0.10	3.2	2.0	10.4	10.0
0.10–0.05	1.6	0.7	4.0	3.6
0.05–0.02	0.4	0.1	0.8	0.3
<0.02	1.1	0.2	0.7	0.9

*Cecil clay, mechanical analysis 30.9% sands, 16.2% silt, 52.9% clay.
†Mean values of five replicates.

APPARATUS

The apparatus employed in the proposed method consists of a used "Whirlpool" washing machine which was rebuilt into an aggregate analysis machine. The tub of the machine was converted into a constant-temperature bath. Five cylindrical containers[4], each 6 inches in diameter and 14 inches high, are placed in the water bath. These vessels are supported on a false bottom or grid work located about 2 inches above the agitator fan which is driven by a shaft extending through the true bottom of the tub. Into each cylinder is placed a nest of 5-inch, brass-framed sieves or screens which have openings of 5 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm (60-mesh), and 0.10 mm (140-mesh).

The sieve junctions are made water tight by placing 1-inch rubber bands, cut from a 4.5 inch innertube, around the nests at appropriate points. Each screen nest is clamped together and against a ¼ x 1 x 5½ inch brass plate placed across the top screen frame by means of 3/16 inch hook-bolts made from bronze welding rod. A ¼ x 4 inch stud mounted vertically at the center of the brass plate serves to connect the nest to the lift mechanism.

The machine is further equipped with an angle-iron framework which supports an elevated deck to which is attached a suitable gear mechanism for raising and lowering the nests of screens through a controlled distance at a controlled rate. A small panel board carries a thermostatic switch, pilot light, and other appropriate switches. Power for operation is obtained from a small motor located beneath the tub.

The entire apparatus, screens excepted, can be collected and assembled at a very meagre cost. The screens, however, cost about $10.00 per nest. The apparatus is shown completely assembled in Fig. 2.

PROCEDURE

Five liters of water are placed in each cylindrical vessel and the containers are then placed in the water bath. The *dry* screens are assembled into nests and then

[4]A six-unit set-up would be desirable.

FIG. 2.—Aggregate analysis apparatus completely assembled.

immersed in the water in the cylinders. The nests are then attached to the lift mechanism and minor height adjustments are made to bring the top screen of each nest into such a position that it just remains covered with water when the lift mechanism is at top dead center.

Fifty-gram samples of air-dry soil are added to each nest and the nests are mechanically raised and lowered through a distance of 1¼ inches at a rate of 30 oscillations per minute for a period of 30 minutes. In most instances, the slaking reaction has been completed and the aggregates have become fractionated on the various screens in somewhat less time than the above-mentioned interval. The machine is then stopped and the sieve nests are raised above their respective containers and allowed to drain.

The sieves are then separated, placed on 6-inch petri dishes, put in an 110°C oven, and allowed to dry completely. Then the dried aggregates are removed from the screens and weighed.

The cylinders containing all particles less than 0.10 mm diameter are allowed to remain undisturbed for a time corresponding to the sedimentation interval of 0.05 mm particles and then the suspension is decanted. The 0.10 to 0.05 mm group may be purified by thrice repeated sedimentation and decantation in and from a 500-ml glass cylinder. (The total quantity of particles less than 0.10 mm seldom exceeds 4 or 5% of the total sample except in the case of silty soils of low organic matter content.) If it is desired, the suspended material may be further divided at 0.02 mm—a logical and practical point of division—in the manner mentioned above.

The remaining suspension solids are then flocculated with aluminum sulfate and the clear water is discarded.

The smaller aggregate fractions are easily handled on Buchner funnels if one uses oversized filter paper and a false, metal inner-wall in the funnel to give the filter paper a cup shape. These fractions are also dried at 110°C before weighing.

The above-described apparatus and methods have been used for 2 years in routine laboratory work in connection with the study of certain physical properties of soils in relation to erosion control and tillage practices. The results obtained have been of practical application to these problems.

AGGREGATE DISTRIBUTION IN THE CECIL SERIES

Aggregate studies were made on a number of Alabama soils from the Cecil series on which Davis (3) had collected much information. Soils varying in clay content from 5 to 55% were selected. When aggregate analysis of these soils were made on samples in the *air-dry* condition, a family of closely related aggregate distribution curves was obtained. The results of this study are pictured in Fig. 3.

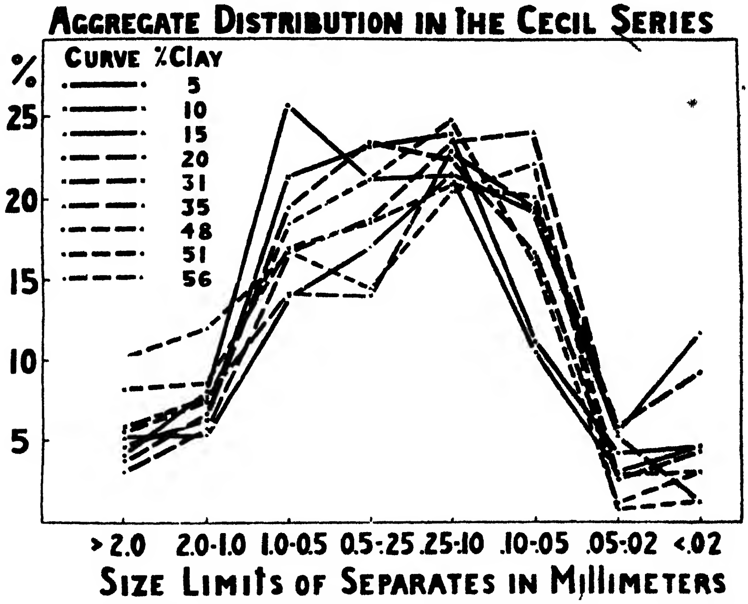

FIG. 3.—Aggregate distribution in Cecil soils of various clay content.

The distribution of water stable aggregates in a large number of samples of soils from important series of the southeastern states has been studied. Several rather contrasting types of aggregate distribution are presented in Fig. 4.

PHYSICAL NATURE OF EROSION LOSSES FROM CECIL CLAY

The physical nature of erosion losses from Cecil clay is but one of several phases of the erosion process which have been studied on the erosion plats of the Agricultural Engineering Department at Auburn, Ala. The general nature of the controlled plat set-up is shown in Fig. 5. Briefly stated, it consists of 10 plats each 15 feet by 50 feet. Two plats are located on each of a 0%, 5%, 10%, 15%, and 20% slope. The soil is a Cecil clay (see Table 3) and is uniform in texture of surface and of subsoil from plat to plat. Suitable equipment and methods are used for (a) measuring rate and amount of natural rains, (b)

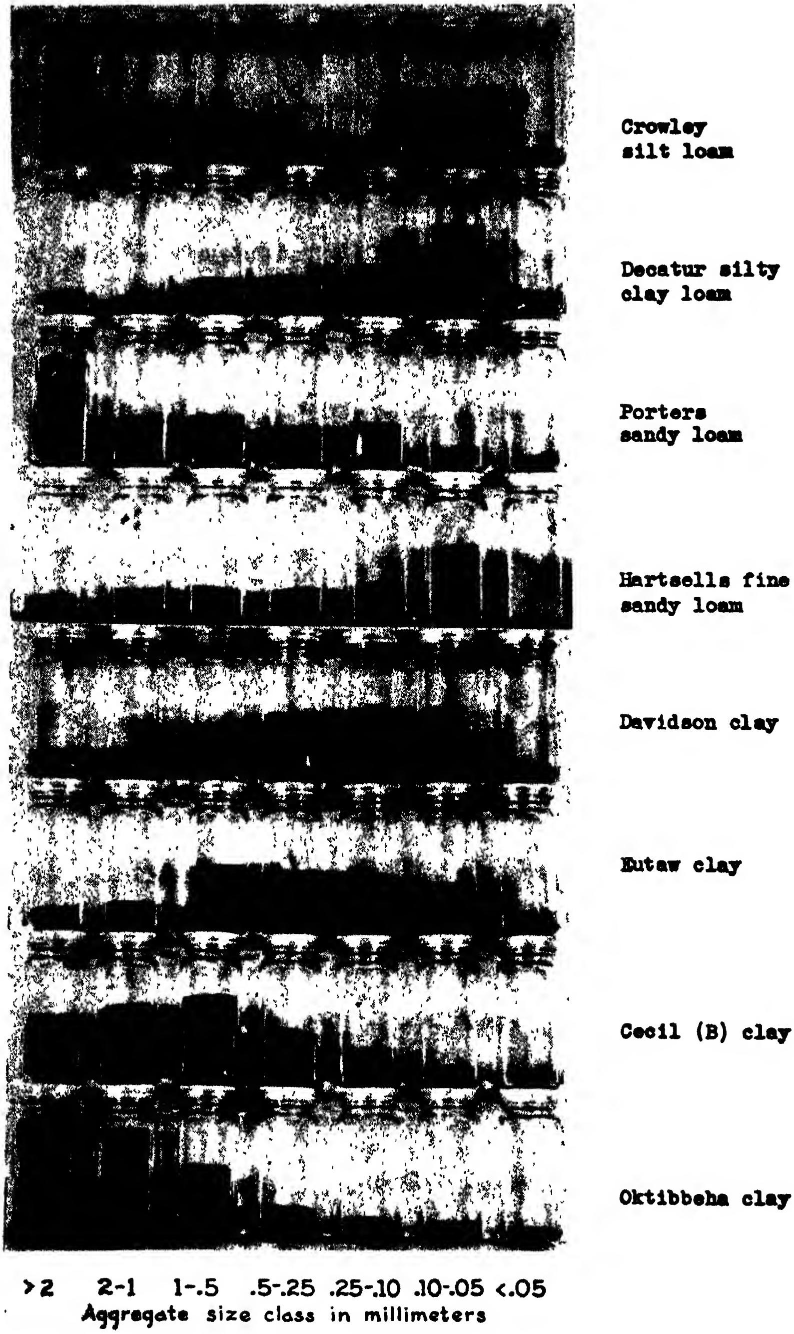

FIG. 4.—Water-stable aggregate distribution in soils from different series.

TABLE 3.—*Influence of vetch at different stages of growth on the physical nature of erosion losses from Cecil clay.*

Mechanical analysis of soil (textural separates)		Aggregate size class of eroded sediments.	Aggregate losses in % of total soil losses for slope of									
			0%		5%		10%		15%		20%	
mm	%		Fallow	Vetch	Fallow	Vetch	Fallow	Vetch	Fallow	Vetch	Fallow	Vetch
			Losses From 3.92 Inch Natural Rain; Vetch about 50% Ground Coverage									
		>2.0	2.6	1.2	3.4	1.3	14.3	3.4	10.3	4.6	4.4	3.9
2.0 –1.0	0.9	2.0 –1.0	5.0	2.3	9.0	2.2	14.3	4.5	9.5	5.1	9.8	4.5
1.0 –0.5	2.4	1.0 –0.5	9.5	3.8	13.2	6.0	15.5	5.6	10.5	8.1	12.0	8.9
0.5 –0.25	5.4	0.5 –0.25	9.0	4.8	13.9	6.7	11.2	6.4	13.3	9.6	15.0	12.0
0.25–0.10	13.4	0.25–0.10	12.6	8.4	13.5	7.4	13.6	11.8	16.3	17.2	18.6	19.0
0.10–0.05	9.2	0.10–0.05	9.5	9.9	18.3	14.4	13.9	15.4	18.6	16.6	17.9	17.4
<0.05	68.7	<0.05	51.8	69.6	28.7	62.0	17.2	52.9	21.5	38.8	22.3	34.3
0.05–0.005	16.3											
<0.005	52.4	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			167	139	8,247	620	26,354	843	42,915	2,574	54,233	4,527
Run-off, cu. ft. per acre			3,550	3,380	10,755	8,915	10,860	8,850	11,335	9,220	12,875	8,065
			Losses From a 2.50 Inch Artificial Rain; Vetch Giving Complete Ground Cover									
		>2.0	3.1	Nil	3.0	Nil	10.4	1.1	6.7	1.5	4.5	1.6
2.0 –1.0	0.9	2.0 –1.0	4.0	Nil	4.3	Nil	11.1	2.7	9.3	3.9	8.4	3.5
1.0 –0.5	2.4	1.0 –0.5	7.5	Nil	18.0	Nil	16.3	5.0	15.8	6.0	14.0	8.5
0.5 –0.25	5.4	0.5 –0.25	6.6	Nil	19.1	Nil	14.3	4.2	16.4	5.6	14.2	12.7
0.25–0.10	13.4	0.25–0.10	19.8	Nil	16.3	Nil	18.0	10.3	19.4	9.7	24.1	11.4
0.10–0.05	9.2	0.10–0.05	14.1	Nil	13.0	Nil	11.2	6.9	10.4	7.7	12.7	8.8
<0.05	68.7	<0.05	44.9	100.0	26.3	100.0	18.7	69.8	22.0	65.6	22.1	63.5
0.05–0.005	16.3											
<0.005	52.4	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			227	8	11,188	6	30,150	26	34,384	48	42,519	521
Run-off, cu. ft. per acre			5,260	3,610	7,600	4,660	7,870	4,610	8,260	4,830	8,770	5,320

FIG. 5.—View of plat layout for sheet erosion studies, Alabama Agricultural Experiment Station.

supplying uniformly distributed, artificial rainfall at any desired rate and amount, (c) measuring rate and quantity of runoff, and for (d) measuring rate and amount of soil losses.

These plats were primarily designed to study between-terrace or sheet erosion, since the construction and maintenance of proper terraces is generally conceded to be the first step in any sound, long-time program of soil conservation and fertility maintenance in the Southeast.

Aggregate distribution determinations have been made on representative samples of soil material eroded from the above-mentioned plats under a wide variety of soil conditions during the past 2 years. A small portion of the results obtained are presented in order to show the importance of considering soil aggregation in investigational work dealing with erosion control. The wet screening or sieve method of aggregate analysis was used.

The influence of vetch at two different stages of growth on the physical nature of erosion losses may be studied from data presented in Table 3. Data from fallow plats are given for comparison. That aggregates rather than textural separates (sands, silt, and clay) are the particles primarily involved in the erosion process in the case of structural soils, is revealed by a comparison of the mechanical analysis of the soil and of the aggregate analyses of sediments actually eroded from the various plats.

The amount of any given aggregate separate eroded may be obtained by simple calculation from the data given in Table 3. In all cases the cover crop has functioned by filtering out or holding in place large quantities of the coarser separates.

The influence of winter legumes on sheet erosion losses has been studied in considerable detail on the controlled field plats. It has been found that cover crops of this type are effective in reducing sheet erosion losses by (a) minimizing the mechanical dispersion

action of beating rain, (b) decreasing the velocity of run-off and hence decreasing the transporting power of water, (c) decreasing the quantity of run-off, (d) decreasing the turbulence of run-off and hence lessening the abrasive action of sediment-loaded water, and (e) by actually filtering out or holding in place the large water stable aggregates. This type of "vegetative control" practice markedly reduces sheet erosion losses; the soil is held in place. The effect of introducing vetch as a winter legume into continuous cotton culture on the quantity of soil losses over a period of 1 year may be seen from the data given in Table 4.

TABLE 4.—*Erosion losses from continuous cotton with and without winter legumes.**

Period of year	Soil losses in pounds per acre for slope of							
	5%		10%		15%		20%	
	Cotton	Cotton and vetch	Cotton	Cotton and vetch	Cotton	Cotton and vetch	Cotton	Cotton and vetch
Cotton season, June–Oct., inc.	18,883	16,344	62,434	62,419	113,800	110,088	138,465	132,493
Vetch season, Nov.–May, inc.	27,564	3,784	90,218	6,392	135,179	14,767	182,662	19,675
June 1934 to June 1935	46,447	20,128	152,652	68,813	248,979	124,855	321,127	152168

*Total rainfall for the year was 45.4 inches; cotton season, 21.1 inches; vetch season, 24.3 inches. Vetch used as winter legume planted in drill rows on contour.

Aggregate analyses were also made on sediment samples eroded from the Cecil clay plats on the various slopes when the soil was protected by different widths of strip crop which consisted of vetch at or near a stage of maximum vegetative growth. Artificial rainfall was applied at constant rate and amount when the soil was at low field moisture and again when the surface horizon was saturated with water. Fallow and freshly plowed plat results may be used as comparative check plats in studying these data which are presented in Tables 5 and 6.

The quantity and nature of sediments eroded and the quantity of run-off from two slopes are presented in Table 5. These data show that the strip crop functions by filtering out the coarser aggregates. A summary of the results obtained with the use of various widths of strip crop on the several slopes under controlled conditions is given in Table 6. The width of strip crop required to perform the filtering process is narrow even on a 20% slope.

While these results are impressive, it would be well to bear in mind that a large portion of the reduction in losses through the use of strip crops is apparent only. Soil is sheet-eroded from the non-protected strip and deposited in the filter strip. Neglecting the several unanswered practical farm problems introduced by strip cropping,

TABLE 5.—*Influence of strip cropping on the physical nature of erosion losses from Cecil clay.**

Mechanical analysis of soil (textural separates)		Aggregate size class of eroded sediments,	Slope width of strips†									
			12.5 ft. plowed, 37.5 ft. vetch		25 ft. plowed, 25 ft. vetch		37.5 ft. plowed, 12.5 ft. vetch		50 ft. plowed, no vetch		50 ft. fallow, no vetch	
mm	%		F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd
			Aggregate Losses in % of Total Soil Losses on 5% Slope									
		>2.0	Nil	Nil	Nil	0.2	Nil	0.1	Nil	0.4	2.1	2.6
2.0 –1.0	1.2	2.0 –1.0	Nil	Nil	Nil	0.2	Nil	0.1	Nil	0.8	2.4	5.9
1.0 –0.5	2.9	1.0 –0.5	Nil	Nil	Nil	0.4	Nil	0.1	Nil	1.7	9.2	15.3
0.5 –0.25	6.4	0.5 –0.25	Nil	Nil	Nil	0.3	Nil	0.1	Nil	2.1	12.5	11.1
0.25–0.10	13.0	0.25–0.10	Nil	Nil	Nil	0.8	Nil	0.2	Nil	3.3	23.9	19.1
0.10–0.05	8.5	0.10–0.05	Nil	Nil	Nil	0.4	Nil	0.3	Nil	3.3	16.1	13.8
<0.05	68.0	<0.05	100.0	100.0	100.0	97.7	100.0	99.3	Nil	88.4	34.0	32.2
0.05–0.005	15.9											
<0.005	52.1	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			12	64	38	177	31	293	Nil	1,277	5,027	4,541
Run-off, cu. ft. per acre			960	2,870	1,071	2,839	419	3,358	Nil	3,002	3,195	3,875
			Aggregate Losses in % of Total Soil Losses on 20% Slope									
		>2.0	1.1	1.8	0.3	0.2	0.2	0.1	1.9	7.7	8.6	6.8
2.0 –1.0	0.8	2.0 –1.0	1.6	2.4	0.4	0.4	0.2	0.2	2.0	10.6	13.4	7.8
1.0 –0.5	2.4	1.0 –0.5	4.9	5.3	1.2	1.2	0.6	0.4	5.9	14.2	15.9	12.0
0.5 –0.25	5.5	0.5 –0.25	3.5	5.7	1.4	0.8	1.2	0.8	4.8	12.1	11.7	13.3
0.25–0.10	13.7	0.25–0.10	15.2	9.2	1.8	2.7	2.2	1.9	17.2	17.7	13.0	11.8
0.10–0.05	9.1	0.10–0.05	11.4	6.4	2.9	2.3	3.6	4.9	20.2	13.8	11.1	10.1
<0.05	67.5	<0.05	62.3	69.2	92.0	92.4	90.0	91.7	48.0	23.9	26.3	38.2
0.05–0.005	16.1											
<0.005	52.4	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			37	181	156	625	231	1,363	1,794	39,980	25,152	12,377
Run-off, cu. ft. per acre			1,295	3,360	1,129	2,924	885	3,115	450	3,495	3,684	3,902

*Losses from 1.25 inch artificial rainfall in 11 minutes in all cases
†Slope width of all plats = 50 feet; strip crop below plowed area; plowing done immediately before tests in all cases; F.M. = soil at low field moisture; Sat'd = surface soil saturated, i.e., at maximum water-holding capacity.

TABLE 6.—*Influence of various strip cropping practices on the quantity of sheet erosion losses from Cecil clay.**

Slope %	Soil losses in pounds per acre with slope width of strips†										
	None plowed, 50 ft. vetch‡	12.5 ft. plowed, 37.5 ft. vetch		25 ft. plowed, 25 ft. vetch		37.5 ft. plowed, 12.5 ft. vetch		50 ft. plowed, no vetch		50 ft. fallow, no vetch	
		F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd
5	2	12	64	38	177	31	293	Nil	1,277	5,027	4,541
10	33	14	67	28	255	117	377	127	3,743	10,238	6,356
15	33	20	128	29	419	142	632	217	19,402	18,778	9,287
20	107	37	181	156	625	231	1,363	1,794	39,980	25,152	12,377

*Losses from 1.25 inch artificial rainfall in 11 minutes with vetch at full ground coverage in all cases except column 2.

†Slope width of plats = 50 feet; strip crop below plowed area; plowing done immediately before tests in all cases; F.M. = soil at low field moisture; Sat'd = surface soil saturated, i.e., at maximum water-holding capacity.

‡1.08 inch natural rainfall with vetch at approximately 90% ground coverage.

the basic fact remains that sheet erosion is actually not being controlled in the most desirable manner by this type of practice. From the soil loss viewpoint the strip acts similarily to a terrace; that is, a certain portion of the suspended particles are deposited. However, the water of run-off is not conducted away but rather is allowed to continue on down the slope. Upon many soil types on moderate slopes, under certain systems of agriculture at least, "vegetative control" methods should be used to support rather than to replace terracing.

SUMMARY

1. The inherent weaknesses of the elutriation method of aggregate analysis are pointed out and the use of this method of aggregate analysis is questioned.

2. A mechanism is suggested to account for the slaking reaction of soils in the presence of excess water.

3. A direct method, with suitable apparatus for determining the water stable aggregate distribution in soils, is reported.

4. Several soils of the Cecil series with widely varying clay contents were found to have similar distribution of water stable aggregates.

5. Soils from different series were found to be characterized by different distributions of water stable aggregates.

6. The physical nature of the erosion process was studied on carefully controlled field plats of Cecil clay located on several slopes. The losses from this strongly aggregated soil occurred primarily in the form of water stable aggregates.

7. Data are presented which show the effectiveness of winter legumes in controlling sheet erosion losses. The manner in which this type of "vegetative control" functions is reviewed.

8. Results on the use of various widths of strip crop for controlling sheet erosion are presented. The basic weakness of this type of "vegetative control" practice is pointed out.

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TENSIOMETERS FOR MEASURING THE CAPILLARY TENSION OF SOIL WATER[1]

L. A. Richards and Willard Gardner[2]

NUMEROUS expressions, such as "soil pull", "saugkraft des Bodens", and "force de succion du sol", have been used in the literature to refer to the security with which water is held by soil. With the development of a clearer understanding of the physical relationships involved, this property of soil began to be associated with the condition of the soil moisture, thus leading to the use of such terms as capillary potential, capillary pressure, suction pressure, pressure deficiency, and tension or capillary tension.

Referred to atmospheric pressure as the zero reference, the pressure in water in an unsaturated soil is negative and it will occasionally be desirable to use the term tension or capillary tension as a name for this negative pressure.[3]

The combination of a porous cell and a vacuum gauge for measuring the capillary tension of soil water was early called a capillary potentiometer (2).[4] Heck (4) has used the name soil hygrometer. Both of these terms admit confusion with other better known instruments. Recently, Rogers (6), lacking a more suitable name, has called the combination a soil moisture meter. In the interest of brevity and unambiguity, the name tensiometer is here used. The designation tensiometer has the further advantage of being more descriptive of the function of the instrument.

Accurately speaking, capillary tension is a magnitude which is defined or exists only in the liquid phase of soil water. From a macroscopic viewpoint, though, it may be thought of as a parameter characteristic of the soil mass and as such has particular experimental usefulness because, like temperature and electrical potential, it can be continuously measured and automatically recorded at a given place without disturbing the soil structure, moisture flow, plant growth, or other process which it may be desirable to correlate with soil conditions.

Porous cups intended for use on tensiometers should be carefully tested to see that they will support the desired water tensions without leaking air. The cups used by the writers were made in the laboratory. Sizes have varied from 0.4 cm in diameter and 2.5 cm long to

[1]Contribution from the Soils Subsection, Iowa Agricultural Experiment Station, Journal Paper No. J329, Project No. 487, Ames, Iowa, and the Physics Department, Utah Agricultural Experiment Station, Logan, Utah. Experimental work in connection with the apparatus here described was undertaken by the authors at the Utah Agricultural Experiment Station as part of Utah Station Project 17, in cooperation with the Bureau of Agricultural Engineering, U. S. Dept. of Agriculture. The work was continued at Cornell University where the senior author was Instructor in Physics. Received for publication February 22, 1936.

[2]Research Assistant Professor of Soils, Iowa Agricultural Experiment Station, and Physicist, Utah Agricultural Experiment Station, respectively.

[3]There is ample precedent in physics and engineering for using tension to refer to a state of negative stress. When dealing with soil moisture, the terms tension or capillary tension need never be confused with surface tension or vapor tension because these latter are always used in the form just given.

[4]Figures in parenthesis refer to "Literature Cited", p. 358.

6 cm in diameter and 20 cm long, the choice being determined by the soil space available or the extent of the soil region over which a knowledge of the capillary tension is desired.

The terms "indicating", "recording", and "differential", describe three general types of tensiometers. The following are some typical arrangements which were set up during the summer of 1931 and have been employed in various soil moisture studies since that time.

INDICATING TENSIOMETERS

The form of this type of tensiometer will depend entirely upon the conditions under which it is to be operated. For the small cups, fine-bore mercury manometers are best, but for field work Bourdon gauges with their greater ruggedness have been used to advantage. It is best to have rigid walls for the closed, water-containing system, any rubber connection being as short as possible and made with vacuum tubing. Any gauge will require some transfer of water between cup and soil to change its reading. The smaller this transfer and the larger the area of soil over which it is spread, the greater will be the speed and accuracy with which the gauge indicates changes in the soil water tension.

It is, of course, necessary that good capillary contact be maintained between the porous cup and the soil. By using a flexible rubber connection to the cup or a rigid support for the vacuum indicator, or both, there has been no difficulty satisfying this requirement.

It is important to be able to detect and remove any air which accumulates in a tensiometer. When space permits it is desirable to have the bore and slope of the tensiometer tubes sufficiently large that accumulated air will of itself rise to an upper chamber where it can be detected and removed. A convenient arrangement for this purpose is shown in Fig. 1.

A ½-inch brass pipe cap with its threads removed on a lathe was drilled, threaded, screwed about ¾-inch onto the end of a ¼-inch brass nipple, and soldered in place as shown at Fig. 1, A. The inverted glass tube B, selected to fit in the resulting annular space, was sealed in place with litharge and glycerine cement. A section of ⅛-inch copper tubing, extending to the top of the glass chamber, was brought out the side of the brass nipple through a solder joint at C. Another section of copper tubing was soldered into the brass T, as shown at D.[5] A ½-inch copper tube (not shown) connected to the gauge with rubber tubing, passed downward through the hole E to the porous cell in the soil. Weather protection was provided by a cover fitting down over the top of the gauge. By placing tube D in a vessel of water and applying suction to tube C, the system may be completely filled. The rubber tubes are then closed with screw clamps. It is advisable to use only best quality vacuum rubber tubing.

Air tends to accumulate in tensiometers which are in operation.

[5]For the gauge connection described above it was found that occasionally, while the tensiometer was in use, air rising from the porous cell would lodge where tube C enters the ¼-inch pipe nipple. To avoid this it will be desirable in constructing new apparatus to replace the two vertical ¼-inch pipe sections shown in Fig. 1 with ⅜-inch pipe.

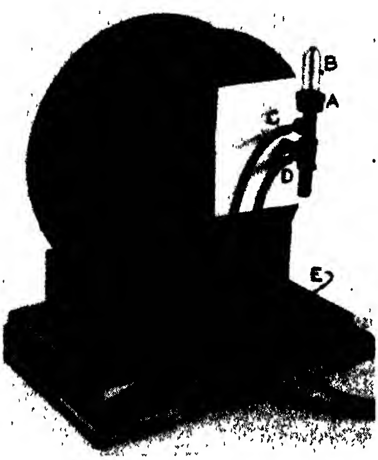

FIG. 1.—Rear view of an industrial vacuum gauge which has been used as a recording tensiometer. See text for a discussion of the arrangement for air detection and removal.

Careful procedure can minimize leaks in connections and through the porous walls of the tensiometer cup, but experience indicates that the water transfer between porous cup and soil which is necessary to change the gauge reading may cause an accumulation of air in the cup because of the effect of pressure on the solubility of gases in liquids. For instance, rain water saturated with air will flow into the porous cup and reduce the gauge reading. The increase in tension which accompanies a subsequent drying of the soil will cause some of this air to come out of solution in the cup. The infusion of air by this process is fairly slow but gauges giving the capillary tension near the soil surface will ordinarily require air removal about once a week.

The presence of air will make a gauge more sluggish in response and the temperature effect on the pressure of the enclosed gas makes it difficult to obtain equilibrium readings.

Bordas and Mathieu (1) have devised a quick-reading tensiometer employing a mercury manometer as the tension indicator. On their instrument the lower part of the mercury manometer is made of rubber tubing so that by raising or lowering the open side of the manometer it is possible to adjust the cup water tension until transfer of water between cup and soil ceases. A drift in the level of the mercury in the closed side of the manometer indicates a flow of water through the cup wall.

The use of tensiometers for studying moisture conditions in the field has been discussed recently by Heck (4) and Rogers (6).

RECORDING TENSIOMETERS

By making use of a recording vacuum gauge it is possible to obtain a continuous record of the capillary tension in soil. Industrial gauges, having a range from 0 to 30 inches of mercury, have been used by the authors for this purpose.[6] The mounting and connections for one of these gauges is shown in Fig. 1 and a typical chart showing, for a period of 1 week, the variation in the capillary tension at a depth of 1 foot in a loam soil is shown in Fig. 2. The sudden drop in the curve occurred at the time of irrigation. The gradual rise indicates the rate at which the capillary tension increased with drying out of the soil.

[6]These gauges, purchased from the Consolidated Ashcraft Hancock Co., Inc., Bridgeport, Conn., were chosen for the purpose because the Bourdon spring with its semi-circular shape can be easily filled and kept full of water.

Five of these instruments have been set up and used in field work and have given highly satisfactory results over a period of years. The results of these investigations will be published elsewhere.

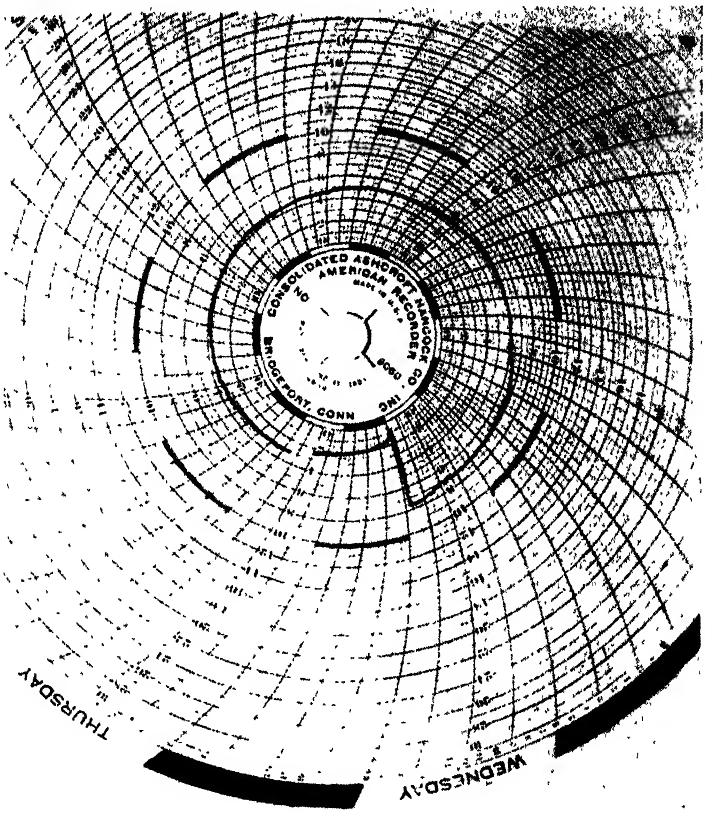

FIG. 2.—Chart from a recording tensiometer showing the variation of the capillary tension at a depth of 1 foot in a loam soil. The sudden drop in tension shows the effect of an irrigation.

DIFFERENTIAL TENSIOMETERS

If two porous cups are filled with water and connected to the two sides of a mercury manometer, the mercury will indicate the difference in the soil water tension at the two cups. Such a system, called a differential tensiometer, provides a convenient means for indicating which way water is moving in a soil. If the two cups are buried in soil and are at the same level, gravity exerts no force to move water from one cup to the other. But, if there is a difference in the capillary tension of the soil surrounding the two cups, the water will flow through the intervening soil in the direction of the cup having the higher tension. Even when the cups are not on the same level, water will move through the soil toward the cup which is connected

FIG. 3.—A differential tensiometer.

to the arm of the manometer containing water at the higher tension. In this case, however, gravity forces enter as a factor determining the flow.

In Fig. 3 is shown a photograph of a differential tensiometer made up so that it can be transferred easily from one place to another in the field and pushed into the soil to indicate the direction of the vertical motion of the soil water. Porous sections, shown at A and B, were mounted by means of DeKhotinsky cement in the side of a 5/8-inch brass pipe. The porous section A was removed for the photograph. The space behind section A is closed off and connected to the 5/16-inch copper tube C, which is attached to the left side of the glass manometer D. The space behind B connects directly to the right side of D. The stop cocks, arranged as indicated, make it easy to fill the system with water and to set the reading at zero. With this construction the porous sections may be pushed into the soil to the desired depth without seriously disturbing the soil structure, and an indication of the direction of flow may be obtained in a few minutes. When an equilibrium reading is obtained the average water moving force (w.m.f.) acting in the soil region between two cells is

$$(\text{w.m.f.})_L = \frac{h\,(d_m - d_w) \times 980}{d_w L} \qquad 2$$

Here d_m and h are respectively the density and difference in level of the differential manometer liquid, d_w is the density of the water, L is the distance in centimeters between the two porous cups, and $(\text{w.m.f.})_L$ is the average water moving force in dynes per gram acting in the direction of the line L connecting the two cells. This result is independent of the orientation in space of the line L and the force acts in the direction of the flow.

The differential tensiometer shown in Fig. 3 was inserted in a loam soil with the porous sections at depths of 6 and 14 inches, respectively, below the soil surface and observations were made over a period of 6 weeks. These observations showed that after an irrigation, when the soil had received a thorough soaking, the flow was downward, but this flow decreased

gradually until after several days it was upward for short periods during daytime evaporation. As the top soil dried out still more the periods of upward flow lengthened until, for several days before the next irrigation, the flow was upward both day and night.

Care must be exercised to avoid having the porous sections of a differential tensiometer too far apart. If the capillary tension at some intervening point is greater than or less than the value of the capillary tension at both porous sections, the state of flow cannot be predicted from one set of readings.

In general, the design of a differential tensiometer will depend on the conditions under which it is to be employed. For certain uses the porous sections should be smaller and closer together than those shown in Fig. 3. More sensitivity in the differential manometer may be obtained by using a manometer liquid less dense than mercury. Also, where desired, an open tube manometer may be attached to read the tension of the water at one of the porous sections.

RANGE AND CALIBRATION OF TENSIOMETERS

The range of capillary tension for which tensiometers can be used does not exceed one atmosphere. This is but one-sixteenth of the tension range in going from saturated soil to the wilting point. On a moisture content scale, however, it is found that the major part of the range suitable for plant growth lies in the tension range of 1 atmosphere. For Greenville loam, for instance, 1 atmosphere of tension covers 85% of the moisture content range which will permit plant growth.

In some investigations which involve a consideration of the movement of water through soil or the effect of moisture on life processes in soil, it is likely that capillary tension will be a satisfactory and perhaps the most suitable magnitude for expressing soil moisture condition Tensiometers are particularly well adapted for use in experiments where different soil treatments on adjacent plats are tested for their effect on soil moisture. In such cases, it will often be unnecessary to know the relation between capillary tension and the moisture content of the soil.

However, when it is desired to go from tensiometer readings to moisture content, experimentally determined calibration curves must be used. A number of examples of these curves and methods for their determination are to be found in the literature (1, 4, 5, 6).

There is a temperature effect which will shift these curves slightly because for a given physical structure and moisture content the capillary tension is proportional to the surface tension of the soil water. Hence, a change in temperature will produce the same percentage change in both the surface tension and capillary tension. The data in Table 1 taken from the International Critical Tables indicate the magnitude of this effect for water. At 20° C it is seen that a 5-degree temperature change causes about a 1% change in the surface tension. The percentage correction to apply to a capillary tension reading which is to be used in connection with a calibration curve made at a different temperature will be the same as the percentage

change in the surface tension between the two temperatures and may be readily calculated.

TABLE 1.—*The surface tension of water in dynes per cm at various temperatures (°C).*

°C	Surface tension, dynes per cm	°C	Surface tension, dynes per cm
0°	75.64	30°	71.18
10°	74.22	40°	69.56
20°	72.75	50°	67.91

The possibility of a hysteresis effect in the relation between capillary tension and moisture percentage must also be considered. For an aggregation of uniform spherical particles the effect may be large (3, 7). This phenomenon has not been sufficiently studied to make possible any generalizations, but for the soils on which reliable data have been published (6) the moisture content width of the hysteresis loop is not greater than 3%.

SUMMARY

The expression "capillary tension" is used as a name for the negative pressure existing in the water in unsaturated soil and porous cell-vacuum gauge instruments used in its measurement are called tensiometers.

Principles underlying the use of indicating, recording, and differential tensiometers are discussed and apparatus used by the authors is described.

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A COMPARISON OF SOIL MOISTURE UNDER CONTINUOUS CORN AND BLUEGRASS SOD[1]

G. R. FREE[2]

THE importance of close-growing vegetation in reducing erosion and run-off is generally recognized. Little information is available, however, concerning the disposition of the water which is prevented from running off by such cover.

The immediate disposition of rainfall may be classed as follows: (a) Part is intercepted by the cover itself and is lost by evaporation without reaching the soil, (b) part is lost as run-off, (c) part enters the soil by a process generally known as infiltration, and (d) part is temporarily stored on the surface and is available for later infiltration or evaporation. The disposition of that part entering the soil may be divided further into the following classifications: Evaporation and transpiration losses, addition to soil moisture in the zone where it is available for plant growth, and addition to subsoil moisture below this zone. The question dealt with by this paper is, Does the water prevented from running off the land by a close cover crop, such as bluegrass, compared with a cultivated row crop, such as corn, remain in the soil?

LITERATURE

Bennett (1)[3] gives data obtained from plats at some of the soil erosion experiment stations which show that close vegetation is effective in reducing erosion and run-off.

Wilson and Welton (6) found that an evaporation index is of considerable value in determining the optimum application of water for bluegrass. A summary of their data is given in Table 1

TABLE 1.—*Summary of Wilson and Welton data for period of May 1 to Aug. 31, 1934, normal rainfall for period 15.18 inches, evaporation for period as calculated from black atmometer losses 23.94 inches.*

Plat no.	Total water applied, surface inches	Yield of bluegrass, grams per 1,000 sq. ft.
1	21.69	34,615
2	27.69	52,293
3	31.69	46,204
Check*	11.69	22,450

*Check plat received only the rainfall occurring during the period.

It is apparent from these data that bluegrass has a great capacity for utilizing moisture in producing greater yields. If we assume that all moisture applied was lost as evaporation and transpiration, the quantity of water used in the production of 1 gram of crop is between 1,200 and 1,500 grams.

[1]Contribution from Soil Erosion Experiment Station, Clarinda, Iowa. Received for publication February 24, 1936.
[2]Junior Soil Conservationist.
[3]Figures in parenthesis refer to "Literature Cited", p. 363.

Kiesselbach (2) states that the average transpiration requirement of corn in eastern Nebraska is not far from 9 surface inches and that more than two-thirds of the average precipitation of 28 inches for that region is lost in ways other than by transpiration from the corn crop. This figure is a result of potometer experiments which show that about 750 pounds of water are transpired in producing 1 pound of dry shelled corn.

Wallace and Bressman (5) give the following amounts of precipitation as desirable for best corn yields in the central part of the corn belt: May, 3.5 inches; June, 3.5 inches; July, 4.5 inches, and August, 4.5 inches. Optimum mean monthly temperatures together with especially favorable conditions during the critical tasseling period are, of course, included as a part of the specifications for best yield.

PROCEDURE

At the soil erosion experiment station near Clarinda, Iowa, there is a set of control plats used for determining, among other things, soil and water losses from corn, bluegrass sod, and other crops common to the region. These plats are located on Marshall silt loam which is fully described by Middleton, Slater, and Byers (3). Suffice to state here that the soil is loessial in origin and is quite uniform in texture and permeable in structure to a depth of 3 feet. The water table is far below the ground surface and may be disregarded from the standpoint of moisture available for crop growth.

Near these control plats is another set of plats having identical slope length, exposure, and cropping treatments. These latter plats are used only for determination of soil moisture and yields.

Standard 8-inch rain gages and a Fergusson recording gage are located near these plats and furnish a measure of precipitation falling on them.

The procedure followed in sampling these plats for determination of soil moisture is to take four samples from a 3-foot profile at various times throughout the year. The first sample is taken at a depth of 0 to 6 inches, the second at a depth of 6 to 12 inches, the third at a depth of 12 to 24 inches, and the fourth at a depth of 24 to 36 inches. These samples are then oven-dried at a temperature of 105°C and the moisture expressed as percentage of dry weight. Moisture equivalents of the soil for depths of 0 to 13 inches, 13 to 24 inches, and 24 to 45 inches are 30.1%, 31.8%, and 29.3%, respectively. These values are taken from Middleton, Slater, and Byers (3).

For the study covered in this paper, soil moisture data from only two plats of the series were used, namely, one cropped to continuous corn and one cropped to continuous bluegrass sod. Run-off data for the two crops are taken from the corresponding plats in the control series.

RESULTS

Monthly precipitation data for the years 1932, 1933, 1934, and 1935 are given in Table 2, together with the corresponding normals.

The data from 21 borings for determination of soil moisture are presented in Fig. 1. The first boring of the series was made December 5, 1932, and the last on October 3, 1935. A summary of the soil moisture data is given in Table 3, together with mean differences for the four sampling depths and the results of tests of significance of these differences. Any mean difference is considered not significant if odds of less than 30:1 are obtained.

TABLE 2.—*Precipitation, monthly averages.*

Month	Station average, inches				Calculated station normal, inches*
	1932	1933	1934	1935	
Jan.	1.13	0.32	0.51	0.84	0.58
Feb.	0.72	0.08	0.26	0.54	0.49
Mar.	0.44	3.06	0.11	0.26	0.78
Apr	2.33	0.91	0.72	0.61	2.65
May	3.42	3.05	2.55	7.88	4.54
June	5.26	4.11	2.37	7.06	5.42
July	2.32	2.27	1.23	1.41	2.95
Aug.	8.10	5.99	2.14	2.79	3.85
Sept.	1.98	4.21	4.82	5.14	3.70
Oct.	1.20	0.87	2.84	3.03	2.64
Nov	1.14	0.42	3.54	2.50	1.31
Dec.	1.08	1.08	0.13	0.29	0.85
Annual	29.12	26.37	21.22	32.35	29.76

*Calculated from adjacent weather stations and corrected for station results thus far.

It should be stated at this point that run-off from the continuous corn plat for the entire period totaled 6.57 surface inches as compared to 1.06 surface inches from the bluegrass plat. It is readily apparent from the data that instead of extra soil moisture being available in the bluegrass plat the reverse is true; significantly more moisture is found under continuous corn, except in the one depth 24 to 36 inches where the difference is not significant.

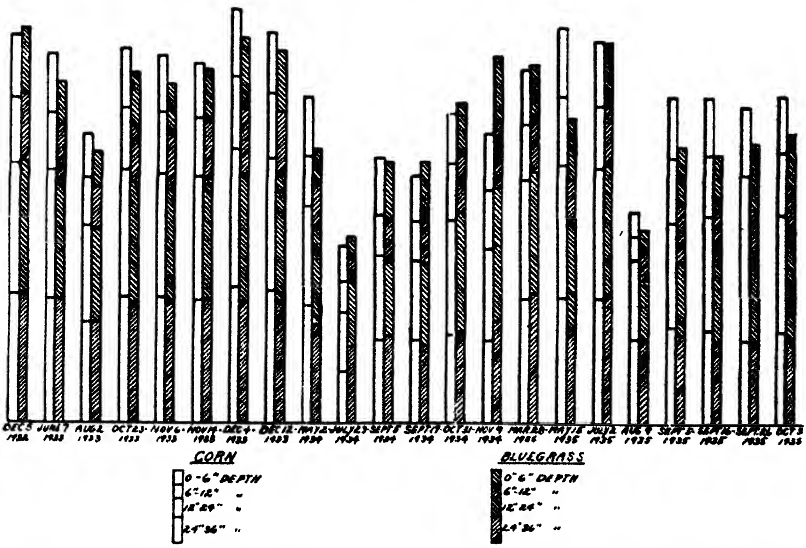

FIG. 1.—A comparison of soil moisture in 3-foot profile under continuous corn and bluegrass.

There remains the possibility that below the 3-foot profile of the bluegrass plat the moisture will be greater, but this is hardly to be expected in view of the significant differences in soil moisture noted above.

TABLE 3.—*Summary of soil moisture data.*

Depth, inches	Average percentage soil moisture		Mean difference	Odds*
	Continuous corn	Bluegrass sod		
0–6	24.38	22.65	1.73	78:1
6–12	24.58	23.33	1.25	30:1
12–24	24.24	22.54	1.70	55:1
24–36	22.83	22.29	0.54	5:1
0–36	23.85	22.61	1.24	78:1

*Determined by Student's method of pairs.

A set of 24 erosion type lysimeters described by Musgrave (4) are located near the plats described above and some data from them will be cited. Percolation from lysimeters of this type containing 3 feet of soil with normal field structure should be indicative of additions to soil moisture below the 3-foot profile in plats where the same cropping practices are followed. At any rate, relative comparisons of percolate from lysimeters with different crops should correspond with relative comparisons of addition to soil moisture below the 3-foot profile in plats with the same crops. From July 1, 1934, to December 31, 1935, the percolation from lysimeters cropped to continuous corn totaled 4.73 surface inches as compared to 1.11 surface inches from corresponding lysimeters planted to bluegrass sod. The absolute difference of 3.62 surface inches in amounts percolated may change as more data are secured, but the relative comparison probably will not.

Since the smaller amount of run-off from bluegrass as compared with corn resulted in neither greater soil moisture content nor greater additions to subsoil moisture below the 3-foot profile, it must be concluded that vapor losses (evaporation and transpiration) great enough to more than offset the extra moisture gained from reduced run-off must have occurred.

It is possible from precipitation, run-off, and soil-moisture data to calculate total moisture losses exclusive of run-off from the 3-foot profile for any period desired. These losses include transpiration, evaporation, and percolation. Table 4 summarizes these losses for the entire period of the study.

TABLE 4.—*Comparison of precipitation and moisture losses.*

	Continuous corn, surface inches	Bluegrass sod, surface inches
Total precipitation	76.49	76.49
Moisture lost as surface run-off	6.57	1.06
Change in moisture content of 3-foot profile (calculated from soil moisture sample data)	—2.14	—3.52
Moisture losses from 3-foot profile other than run-off	72.06	78.95

The percentage run-off of the total precipitation for the period has been 8.6% for continuous corn and 1.4% for bluegrass sod. The sum of transpiration, evaporation, and percolation losses from a 3-foot profile under corn has been 94.2% of total precipitation compared with 103.2% from the profile under the grass cover. The fact that this sum for grass cover is over 100% of total precipitation means, of course, that the net decrease in soil moisture for the period has been greater than the total loss of moisture from run-off.

There is evidence of a cyclical change in soil moisture for both crops. Soil moisture reaches a low point in summer periods when transpiration and evaporation needs are greatest and is replenished during the fall, winter, and spring.

CONCLUSIONS

Soil moisture in a 3-foot profile under continuous corn has been significantly more than that under bluegrass sod despite a difference in run-off of 5.51 surface inches. This difference in available moisture cannot be accounted for by greater additions to subsoil moisture below the 3-foot profile, because under corn, for the period for which percolation data from lysimeters is available, the percolation was greater by 3.62 surface inches.

This condition of less run-off and less soil moisture under bluegrass sod as compared with corn can only be explained by greater evaporation and transpiration losses for the former crop. It is apparent that while the value of a bluegrass sod cover from the standpoint of soil conservation and reduction of run-off is beyond question, the term "moisture conservation" must be used very carefully in order to prevent misunderstanding.

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THE EFFECT OF VARIETY, PLANTING DATE, SPACING, AND SEED TREATMENT ON COTTON YIELDS AND STANDS[1]

G. A. HALE[2]

EXPERIMENTAL data are available on various factors affecting cotton yields and stands where these factors have been studied singly. The work reported here was done with the view of not only determining the highest yielding variety, the best planting date, the optimum spacing of the plants in the row, and the value of treating the seed with Ceresan for the climate and soil (Cecil series) of central Georgia, but also of studying the relationships between these factors affecting yields and stands. A multiple-factor field experiment with cotton or other field crops has many advantages over the common or single-factor experiment where only one variable, such as varieties, is studied.

MATERIALS AND METHODS

Five cotton varieties, three planting dates, three spacings (3 years only), and untreated and treated seed were used for the 5-year period of this experiment. All varieties were planted on each date every year, but only one variety, Stoneville 2, was used in the spacing and seed treatment work. The planting dates, as nearly as soil conditions permitted, were made in late March, late April, and late May, or about one month apart. The spacings tested in 1932, 1933, and 1934 were two plants in hills 1 foot apart with all rows 3.5 feet apart, unthinned plants in hills 1 foot apart, and unthinned plants in hills 3 feet apart. The seed treatment used consisted of dusting the ordinary or undelinted seed with Ceresan (ethyl mercury phosphate).

Eight series of plats for each variety, spacing, and seed treatment were planted on each of the three dates. Eight plats were required to the series except during 1930 and 1931 when only six plats were used because the spacing factor was not included. The series were arranged systematically because of convenience in planting. The plats within each series were randomized or arranged by chance. Seven-row plats with rows 35 feet long and 3.5 feet wide were used. Two or more pickings were made each year and boll samples taken at each picking. The lint yields reported are calculated from lint percentages determined by taking 50-boll samples from each plat at each picking rather than from a single lint percentage determined for one picking and assumed to be correct for all pickings. The number of plants and missing hills were determined on all plats at picking time. All plats were dusted from four to eight times with calcium arsenate to control boll weevils. The results in Table 1 are 5-year averages unless otherwise stated.

VARIETAL EFFECTS

The Half and Half, a medium early maturing variety, was outstanding in lint yield for the average of all plantings and seemed to be especially well adapted for medium and late planting. This variety

[1]Contribution from the Department of Agronomy, Georgia Agricultural Experiment Station, Experiment, Ga. Published with the approval of the Director as Paper No. 44, Journal Series. Received for publication February 6, 1936.

[2]Assistant Agronomist. The author is indebted to R. P. Bledsoe, Agronomist, for suggestions and criticisms offered in the course of this work and in preparation of the manuscript.

made the poorest relative showing when planted early, although it ranked first in lint yield of all varieties at this date. Observation of this variety in other fields where weevil damage was not reduced by heavy dusting indicates that Half and Half is more susceptible to weevil damage than some of the earlier and quicker fruiting cottons. Stoneville 2, a very early maturing variety, ranked second in average yield for all plantings and was a slightly more consistent producer at all planting dates than Half and Half. Piedmont Cleveland, a medium early maturing variety, ranked third in average yield and had the highest relative yield (using yield at medium date as 100) for the early planting of any variety. This cotton was as high in yielding ability as Half and Half and Stoneville 2 when planted in late March at Experiment, but inferior to them when planted later. Lightning Express, an early maturing variety, ranked fourth in lint yield at each planting date, but made the poorest relative yield when planted late. Deltatype, a medium to late maturing variety, produced the lowest yields but made the best relative yield when planted late, indicating that it was not affected as adversely as other varieties by the hot, dry weather and high weevil infestation which usually prevailed during the fruiting periods of the late planted cotton.

The effects of varieties on cotton stands was difficult to measure in this experiment because it was impossible to calibrate the ordinary cotton planter used so that it would plant exactly the same number of seed of each variety tested, and, too, there were some significant differences in the germination of the seed of the varieties during the first-year plantings when the seed were obtained from the breeders. The Lightning Express variety from both observation and the plant and hill counts presented in Table 1 seemed to be outstanding in seedling and plant vigor when sown at all dates. Deltatype produced the poorest stands.

It is obvious from these different responses of the five varieties tested to the three dates of planting that the time when a cotton varietal test is planted may have a marked influence on the relative rank in yield of the varieties tested. From these results, it may be concluded that varietal tests planted either earlier or later than the optimum or usual cotton planting date for a given locality may be of doubtful value in making varietal recommendation.

PLANTING DATE EFFECTS

Some of the effects of planting date on individual varietal yields have already been discussed. The average yield of all varieties for the late March and late April dates is practically the same with a reduction of 240 pounds of lint cotton per acre as a result of late May planting. Since this late planting was made in small blocks in the same 5-acre field with the earlier dates, it is likely that the yield is somewhat less than would be secured from a late planting in an isolated field where weevil infestation could be controlled more effectively.

The effect on yield of planting date with Stoneville 2 Ceresan-dusted seed as compared with the non-dusted seed was not significant. The influence of planting time on the yield of the three spacings in the

TABLE 1.—*Average results showing the effect of variety, planting date, spacing, and seed treatment on cotton yields and stands at Experiment, Georgia, 1930–34.*

Variety and treatments*	Planted early (late March)			Planted medium (late April)			Planted late (late May)			All planting dates		
	Pounds lint per acre	No. plants per acre	No. hills per acre	Pounds lint per acre	No. plants per acre	No. hills per acre	Pounds lint per acre	No. plants per acre	No. hills per acre	Pounds lint per acre	No. plants per acre	No. hills per acre
Lightning Express	540	18,728	10,777	523	20,939	11,466	282	23,010	11,011	448	20,892	11,085
Half and Half	589	16,144	10,210	626	20,241	11,090	347	22,157	11,096	521	19,514	10,799
Deltatype	463	15,148	9,686	460	18,132	10,755	270	21,874	11,046	398	18,385	10,496
Piedmont Cleveland	580	17,757	10,729	534	18,998	10,964	302	21,933	10,968	472	19,563	10,887
Stoneville 2	570	16,741	10,342	565	19,770	10,887	323	23,103	11,064	486	19,871	10,764
Average all varieties	548	16,904	10,349	542	19,616	11,032	305	22,415	11,037	465	19,645	10,806
Stoneville 2, seed not dusted	573	15,976	9,684	572	21,917	11,246	317	24,608	10,659	487	20,834	10,530
Stoneville 2, not thinned, hills 1 foot apart†	536	37,451	11,328	541	32,323	10,731	269	40,985	10,970	449	36,920	11,010
Stoneville 2, not thinned, hills 3 feet apart†	481	17,557	3,965	505	15,972	3,856	272	18,278	3,397	419	17,269	3,739
Stoneville 2, thinned to 2 plants 1 foot apart†	563	19,129	11,469	541	17,378	10,537	303	17,340	10,872	469	17,949	10,959

*Ceresan dusted and plants spaced 1 foot apart with 2 plants per hill unless otherwise stated.

†3 years only, 1932–34.

row indicates that this factor may be of importance in conducting spacing experiments. The standard or considered optimum spacing of two-plant hills 1 foot apart was relatively better for the early and late dates than the other two spacings. Contrary to expectations, the late cotton gave best yields from the thinnest spacing.

The planting date had considerable influence on the stands as measured by both the number of plants and number of hills per acre. By preparing the seedbed and applying 400 pounds per acre of an 8-4-4 (P-N K) fertilizer several days before planting and seeding at the rate of 1½ bushels of seed per acre in hills, fairly good stands were obtained every year at all dates. The first planting gave the most irregular stand and the third or latest seeding the best stand.

SPACING EFFECTS

Some of the relationships between spacings and planting dates have been discussed. Although the spacing work is for only 3 years and with only one variety, the results are informative. Two plants per hill and hills 1 foot apart produced 27 more pounds of lint per acre than the next best spacing or the unthinned plat with 1-foot hills when planted early and 31 pounds more when planted late; but when planted at the intermediate date, the two spacings yielded the same or 541 pounds of lint per acre. The unthinned cotton in hills 3 feet apart was inferior to the other spacings at all dates. This spacing has an advantage in cultivation as checked cotton can be kept free of weeds with less hoeing than drilled cotton.

SEED TREATMENT EFFECTS

Dusting cotton seed with Ceresan was not effective in increasing yields. The number of plants was largest at the early and late planting with dusted seed, but dusting seemed to reduce stands at the medium planting date.

CORRELATION BETWEEN YIELD AND STAND

The correlation coefficients in Table 2 show some relationships between lint yields and stands for the three planting dates for each of the 5 years where the varieties were compared. Neither the number of plants per acre nor the number of hills per acre was very highly correlated with the lint yields when the cotton was planted early or

TABLE 2.—*Correlation coefficients between the yield of lint cotton and the number of plants and hills per acre for the three planting dates.**

Planting date	Correlations between lint yield and	
	Number of plants per acre	Number of hills per acre
Early (late March)	.322	.419
Medium (late April)	.586	.789
Late (late May)	.307	.480

*According to tables prepared by Snedecor and Wallace in "Correlation and Machine Calculation", where N = 25, the least significant value for r is .388, while the least highly significant value for r is .496.

late, however, the correlation coefficients for yield and hills per acre are significant. Apparently early planted cotton is able to adjust itself to a wide range of spacing without materially affecting yields. The thick stands of the late planted cotton of this experiment masked any effects of variable stands on yields.

The highly significant coefficients for the medium or optimum planting date for the varieties show that both the number of plants and the number of hills affected yields. From these results it may be concluded that the distribution of the plants as shown by the number of hills is of more importance in obtaining high cotton yields than the total number of plants per acre as shown by plant counts.

SUMMARY AND CONCLUSIONS

Five-year average results of a multiple-factor field experiment with cotton cultural factors including varieties, planting dates, spacings, and seed treatments at the Georgia Agricultural Experiment Station are reported in this paper. This type of experiment was found to have a number of advantages over the common single-variable field experiments where only one factor, such as variety or stand, is varied.

Of the five varieties tested, Half and Half and Stoneville 2 were the highest yielders when all planting dates were averaged. The varieties responded differently to the different dates of planting, indicating that the date of planting of varietal experiments may have a marked effect on the relative yields of the varieties and the value of the results for making cotton varietal recommendations.

The varieties showed some significant differences in their ability to produce satisfactory stands, especially when planted early or during late March at Experiment, Ga.

Of the three planting dates studied, the early (late March) planting and the medium (late April) planting produced the same 5-year average annual yields of lint. The late (late May) cotton yielded only about one-half as much lint as was harvested from the earlier plantings. Stands were poorest on the earlier planted cotton and thickest where the seed was sown in May.

Three-year average results are reported with the Stoneville 2 variety spaced as follows in 3½ foot rows: (1) Not thinned, hills 1 foot apart; (2) not thinned, hills 3 feet apart; and (3) thinned to two plants, hills 1 foot apart.

Two plants 1 foot apart produced the highest yields, except for the medium planting date, when the unthinned cotton in hills 1 foot apart made as much cotton as the thinned cotton spaced 1 foot apart. Contrary to common belief, the unthinned cotton was relatively poorer when late planting was done than for the other dates. The number of hills or the distribution of the plants rather than the total number of plants per acre is most important in spacing experiments. The results show that planting date may affect the ratings of different spacings in cotton spacing experiments.

Treating the Stoneville 2 cotton seed with Ceresan had no significant effects on stands or yields under the conditions of this experiment.

Correlation coefficients are presented to show the relationships between annual yields of lint of the five varieties and the total number of plants and hills per acre.

Where the cotton was planted early, although the stands were somewhat irregular during some seasons, there was no significant correlation between the yield per acre and the total number of plants per acre and only a slightly significant correlation between yield and number of hills per acre. The results for late planted cotton, where stands were good every year, were similar to those for early planting.

The medium planting showed a highly significant, positive correlation between lint yield and both number of plants and hills per acre. The number of hills on the variety plats like those on the spacing plats was more closely and positively correlated with the number of pounds of lint cotton produced than with the number of plants per acre. These results indicate that in studying cotton stands the number of hills may be more important than the number of plants per plat or acre.

HYBRID SELECTIONS OF OATS RESISTANT TO SMUTS AND RUSTS[1]

H. C. MURPHY, T. R. STANTON, and F. A. COFFMAN[2]

THE development of smut- and rust-resistant strains of oats from the cross Victoria × Richland has been reported.[3] To obtain hybrid populations for pathological and genetical studies of certain physiologic forms of crown rust and also, incidentally, to obtain strains equally resistant to smut and stem rust and possibly with better adaptation and greater productiveness, some of the important stem-rust resistant varieties were crossed on Bond by the senior writer in the greenhouse at Ames, Iowa, in the spring of 1932.

MATERIALS

The crosses producing the most promising lines that are not only homozygous for resistance to the smuts and rusts but apparently are agronomically desirable, are as follows:

X M328 Bond (C.I.[4] 2733) x Iogold (C.I. 2329)
X M3217 Anthony (C.I. 2143) x Bond (C. I. 2733)
X M3218 Bond (C.I. 2733) x Iowa No. D69 (C. I. 2463)
X M3214 Green Russian sel. (C.I. 2344) x Bond (C I 2733)

Bond was introduced from Australia in 1929. Its history, classification, high resistance to crown rust, and probable agronomic value have been reported by Stanton and Murphy.[5] Bond was nearly immune from all except 2 of 22 physiologic forms of crown rust (*Puccinia coronata avenae* Eriks.) collected in the United States, Canada, and Mexico in 1931-34, inclusive.[6] It was susceptible to rare forms collected in Louisiana and Arkansas only. It is resistant also to collections of loose and covered smut of oats, *Ustilago avenae* (Pers.) Jens. and *U. levis* (Kell. and Sw.) Magn., respectively, obtained from the corn belt, although it has not been uniformly resistant to all collections apparently representing distinct races of the oat smuts from other regions. Bond has an excellent straw, but its complete susceptibility to stem rust (*Puccinia graminis avenae* Eriks. and Henn.) and the pronounced sucker mouth type of hilum make it of doubtful agronomic value. Iogold, Anthony, Iowa No. D69, and Green Russian selection (C.I. 2344) are highly productive, stem-rust resistant varieties, the first two being widely grown and commercially important. All four varieties, however, lack resistance to both smuts and to certain important physiologic forms of crown rust. Iogold has shown no resistance to any of 37 forms of crown rust collected in 1927-35,

[1]Journal Paper No. J-306 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 73. Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station. Received for publication February 12, 1936.

[2]Associate pathologist, senior agronomist, and associate agronomist, respectively.

[3]STANTON, T. R., MURPHY, H. C., COFFMAN, F. A., and HUMPHREY, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24: 165-167. 1934.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations, U. S. Dept. of Agriculture.

[5]STANTON, T. R., and MURPHY, H. C. Oat varieties highly resistant to crown rust and their probable agronomic value. Jour. Amer. Soc. Agron., 25: 674-683. 1933.

[6]MURPHY, H. C. Physiologic specialization in *Puccinia coronata avenae*. U. S. D. A. Tech. Bul. 433. 1935.

inclusive. Anthony and Iowa No. D69 have been resistant to a number of relatively unimportant forms and to the important form 7. Green Russian selection (C. I. 2344) also has been resistant to a number of forms, including some that occasionally are responsible for epiphytotics in the spring-sown oat region. None of these varieties, however, has shown any resistance to the destructive form 1, which is ordinarily responsible for most of the damage caused by crown rust in the United States, especially in the southern states.

METHODS OF HANDLING PROGENIES AND THE RESULTS

The F_1 plants from the four crosses were grown in the cooperative nursery at Ames in the summer of 1932 and were not subjected to any artificial inoculations of smut or rust. In the fall of 1932 some of the seed from these F_1 plants was sown in the greenhouse and the seedling plants were hand-inoculated with physiologic forms 1, 2, and 7 of crown rust and form 2 of stem rust. Plants resistant to all of these forms of both rusts were transplanted into individual pots and grown to maturity. For sowing in the spring of 1933, seed from these resistant F_2 plants was hulled and dusted with a composite collection of loose and covered smut collected from the Ames oat nursery in 1932. Early in the boot stage the F_3 plants were hand-inoculated with the above-mentioned forms of crown and stem rust. The infection resulting from this inoculation was sufficient to allow excellent differentiation for reaction to both rusts. At harvest, several of the F_3 lines were smut-free and apparently homozygous for resistance to both rusts.

Seed from a number of the more promising of these resistant lines was hulled, dusted with smut collected from the smutted F_3 sister lines, and sown in the greenhouse in the fall of 1933. In the seedling stage the plants were inoculated with forms 1 and 7 of crown rust, and at first heading with form 2 of stem rust. A heavy infection of smut was obtained on the susceptible parents and on certain of the families that apparently had escaped infection in the F_3 generation. A few families segregated for reaction to one or both rusts.

In the spring of 1934 remnant seed from all of the resistant F_3 lines grown in 1933 was hulled and dusted with smut collected from the susceptible F_3 sister lines. This seed was sown on April 17 and 18. Non-hulled seed from the resistant F_4 plants grown in the greenhouse was dusted with smut from the same collection and sown on April 27 and 28. Because of the severe drought of 1934, only a few plants grew from the hulled seed sown on April 17 and 18. Excellent germination of the April 27 and 28 sowing was obtained after rains that fell during the last week of June. These rows were irrigated and the early-maturing lines were harvested on September 17, while some of the late-maturing ones were not harvested until October 30. All of the F_5 progenies were harvested as single plants. The reaction to rust of these F_4 and F_5 lines was not obtained because of the complete absence of both rusts. There was a heavy smut infection of the few susceptible lines obtained from the early planting, while there was very little infection of the later planted lines. No smut appeared under field conditions in the lines that were resistant under greenhouse conditions. Previous to sowing in the spring of 1935, the seed

from the individual F_5 plants was carefully selected for absence of the suckermouth hilum present in seed of the Bond parent. Seed from the F_4 and F_5 progenies was not hulled before sowing. It was, however, well blackened with spores of smut collected in the vicinity of Atlantic and Ames, Iowa.

The writers have used Bond as a parent in another cross, *viz.*, Bond (C. I. 2733) × Iowa No. 444 (C. I. 2331), which was not grown continuously at the Agricultural Experiment Station, Ames, Iowa, but from which promising lines have become available. Two hybrids XS1128 and XA1131 of this combination were made by T. R. Stanton and C. Roy Adair, respectively, in the spring of 1933 in the greenhouse at the Arlington Experiment Farm, Rosslyn, Va. The F_1 generation plants were grown at the Aberdeen Substation, Aberdeen, Idaho, in 1933, and the F_2 generation plants from hulled seed inoculated with spores collected at Ames, Iowa, in the greenhouse at the Arlington Experiment Farm in the winter of 1933–34. One-half of the F_2 plants from a common F_1 parent were inoculated with crown rust and the other half with stem rust in the adult stage from cultures received from Ames. At maturity all smutted plants and also all rusted plants showing a type 3 reaction or higher in a 0–4 scale for either rust were immediately discarded. Seed from the resistant plants was bulked and sown in 8-foot nursery rows at the Aberdeen substation in 1934. At harvest only those F_3 plants having desirable plant and grain characters were selected for further testing. Hulled seed from some of the best was dusted with smut from Ames, Iowa, and sown in pots in the Arlington farm greenhouse in the fall of 1934. The seed was inoculated with smut from Ames and the F_4 plants were inoculated with cultures of form 1 of crown rust and form 2 of stem rust, as in the F_2. At maturity only those surviving plants that were smut-free and highly resistant to both rusts were retained. Panicle or head rows from these F_4 plants were sown at Ames in the spring of 1935. The F_5 progenies were subjected to very severe epiphytotics of both rusts. From these progenies only those lines were selected that had satisfactory grain characters, matured normally, and were free from rusts and smuts.

RUST EPIPHYTOTICS, ARTIFICIALLY AND NATURALLY INDUCED, AT AMES

Weather conditions at Ames throughout the season of 1935 were nearly ideal for the development of epiphytotics of both oat rusts. When the oat plants showed first jointing, urediospore suspensions of crown and stem rust were hypodermically injected into susceptible Markton and Carleton plants (mixed, in order to spread the period most favorable for rust inoculation and infection) growing in the alley and border rows. These inoculations were repeated three times during the season and the resulting infection, combined with a heavy natural infection of crown rust and a light infection of stem rust, was so severe as to prevent the production of grain on the Markton and Carleton plants. The rusts spread readily from these susceptible check plants to adjoining rows of hybrid selections. The contrast between the reaction of the resistant and susceptible lines to this

FIG. 1.—Looking across the 5-foot rows and down the alley between series. *Right*, F_6 selections from the cross XM3214 Green Russian selection × Bond, resistant to crown rust, stem rust, and smut. *Left*, F_5 segregates from the cross XM3211 Markton × Bond, susceptible to crown and stem rust, resistant to smut. *Center*, Markton and Carleton (mixed) check growing in alley, susceptible to both rusts, resistant to smut.

very severe infection was striking. Lines resistant to both rusts remained green and erect, ripened normally, and produced high yields. Some of these lines from the cross X M3214 Green Russian selection × Bond are shown in Fig. 1. The leaves of all crown-rust-susceptible plants were killed soon after the panicles were fully exserted. The plants ripened prematurely and produced a low yield of very light grain. All lines susceptible to stem rust lodged early, ripened prematurely, and yielded a very small amount of light grain. Owing to the severe rust infection, the plants were badly lodged before ripening, most of them producing no grain and many of them never heading. The mortality of progenies due to one or the other rust for the nursery as a whole, was exceedingly high. Infection of smut also was abundant on the susceptible lines. All lines previously found homozygous for resistance to the rusts and smuts were outstanding for their resistance in 1935.

CONCLUSIONS

Since the resistant selections considered in the foregoing were subjected in both greenhouse and field to epiphytotics of rust and smut much more severe than those ordinarily occurring under field conditions, it is believed that they will continue to be resistant to natural epiphytotics of these diseases unless some major change occurs in the physiologic-form flora of the corn belt region. These selections appear to be very promising from the standpoint of yield and adaptation, although definite tests of these qualities have not been made.

VARIETAL RESISTANCE OF SMALL GRAINS TO SPRING FROST INJURY[1]

J. B. HARRINGTON[2]

NATURE imposes many limiting factors on crop production and one of these is frost injury to grain crops. On the western plains of Canada and the adjacent areas of the United States, the growing season for spring-sown crops is short, necessitating early sowing, and night temperatures of several degrees below freezing may occur after the grain seedlings have emerged and attained a height of 5 or 6 inches. The plants may be severely damaged with most of the exposed leaf tissues killed. New growth soon replaces the ruined parts, and to the superficial observer the effects of the frost are erased and become a thing of the past. In fact, spring frosts are generally assumed to do little permanent damage to the small grains excepting insofar as the temporary set-back might delay maturity slightly.

It seems more probable, however, that a crop which is badly frosted in the seedling stage suffers permanent injury. In careful work at Fargo, N. D., Waldron (10, 11)[3] calculated that a frost of 6°F reduced the eventual yield of Hope, one of the wheat varieties in his experiment, by 38%. In another test, where the frost was less severe, the loss was much less, but Hope was more injured than any other variety in the test and there appeared to be definite differences in resistance to frost injury with respect to other varieties in the test. Waldron's work indicated that it is a distinct advantage to have varieties with as high a degree as possible of seedling resistance to frost damage.

An excellent opportunity to obtain comparative frost resistance on cereal varieties and hybrids under field conditions presented itself on June 4, 1935, at Saskatoon, Saskatchewan, when a fairly uniformly distributed frost occurred. At this time nearly all of the cereals were in the two-leaf seedling stage and a carefully planned experiment where freezing temperatures could be administered under full control and on an *immense* scale could hardly have produced more satisfactorily differential results.

Before presenting and examining the Saskatoon data, it is of interest to examine some of the recent literature on cold resistance to gain an idea of the amount of reliance to be placed on comparative seedling frost reactions. Martin (5) tested the cold resistance of 12 Pacific Coast spring wheats and found essential agreement between results obtained at the seedling stage and boot stage under both artificial and field conditions. Peltier and Kiesselbach (6), in a study of cold resistance in spring-sown cereals, showed that seedlings in the two and three-leaf stage of development were materially less resistant than seedlings at earlier or later stages of development. Suneson and Peltier (8) reported similarly that "seedlings emerged from 7 to 12 days prior to controlled hardening and freezing,

[1]Contribution from the University of Saskatchewan, Saskatoon, Sask. Received for publication February 28, 1936.

[2]Professor of Field Husbandry. The author is indebted to Messrs. H. Horner, J. Whitehouse, and J. S. Buchanan who took the frost injury notes and made the variance calculations, and to Dr. T. A. Kiesselbach who read the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 387.

and probably on the verge of endosperm exhaustion, were least cold tolerant". Klages (3) earlier had reached the same conclusion in work with nonhardened plants. On the other hand, Tumanov and Borodin (9) concluded from work with winter crops that with artificial freezing methods the frost resistance of seedlings depended largely upon the temperature at which germination took place.

PROCEDURE

The frost of June 4, 1935, injured cereal crops over most of the Saskatoon district. The exact temperatures in the various breeding nurseries during the period of the frost are not known, but the continuous temperature record of the University of Saskatchewan meteorological station situated less than a mile from the cereal nurseries showed the following figures: On June 4 at 1 a.m., 36° F; at 2 a.m., 30°; at 3 a m., 29°; at 4 a.m., 30°; and at 5 a.m., 36°. The thermograph yielding these records was at an elevation of several feet above the level of the nurseries. Furthermore, the elevation of the different nurseries varied by as much as 10 feet and air movement interferences such as tree belts were closer to some nurseries than to others. Therefore, the actual temperatures in the nurseries probably varied somewhat from those shown by the thermograph.

Most of the cereal variety plat tests were located within an area roughly 800 feet by 800 feet in size. Throughout this area the frost damaged some wheats badly and some barleys very badly. Within the area occupied by any one experiment the frost was fairly uniform judging by the damage in distributed plats of standard varieties.

While the nurseries were not all sown at the same time, the emergence throughout occurred within a period of 6 days, and at the time of the frost the cereal seedlings were nearly all in the two-leaf stage with the third leaf commencing to appear in some cases. The flax was in the two-leaf stage for the most part. Most of the data on frost damage were taken on the second and third day after the frost. Each set of data was analysed biometrically for correlation between date of emergence and frost injury, but no relationship was found.

The frost injury was recorded on an individual plant basis, using a scale from 10 to 0 as follows:

Resistance index	Amount of injury
10	None
9	One leaf slightly
8	One leaf moderately
7	One leaf severely
6	Two leaves moderately or one leaf severely and one slightly
5	One leaf severely and one moderately
4	Two leaves severely
3	Two leaves severely and culm slightly
2	Two leaves severely and culm moderately
1	Two leaves and culm severely
0	All above ground parts killed

In a series of 21 1/40-acre plats (132 feet long and 8 feet wide) of cereal and flax varieties, frost data were obtained from the seedlings in 15 randomized 1-foot sections of row in each variety. A total of 10,500 plants was examined. Somewhat similarly, individual plant notes were taken on more than 1,000 seedlings in a series of 1/1000-acre plats.

Frost notes were also taken on five triple rod-row plat tests as follows: The test of new wheats resistant to stem rust, the test of durum and common wheats, the standard barley variety test, the smooth-awn barley test, and the standard oat test. In all of these tests, while the injury to individual plants was the basic consideration, a single estimate of damage was made for each plat.

As resistance and susceptibility to frost injury are related closely in genetic origin, a complete list of the varieties for which data are presented in this paper is given in Table 1, together with the source and origin of each.

In summarizing and analyzing the data, the frost resistance indices were treated as class values differing by equal increments and subject to the same statistical treatment as any other data which assume the shape of the normal

TABLE 1.—*Source and origin of varieties studied.*

Variety	Univ. of Sask. Accession No.	Canadian Accession No.	Source*	Origin
			Wheat	
C. I. 1095 ...	1750	1866	N. Dak. E. S.	Hope x Ceres
C. I. 1121....	1751	1867	U. S. D. A.	Reliance x Hope
Canus.......	1725	1260	Univ. Alta.	Kanred x Marquis
Ceres........	1212	1263	N. Dak. E. S.	Kota x Marquis
E. Triumph..	603	1291	S. Wheeler	Bobs natural cross
Garnet......	791	1316	C. E. F. Ot.	Preston x Riga M
Golden Ball..	1887	1324	U. S. D. A.	South African durum
(H44 - DC) x Ma.......	1701	1861	Univ. Sask.	(H-44-24 x Double Cross) x Marquis
(H44 - DC) x Ma.......	1702	1862	Univ. Sask.	(H-44-24 x Double Cross) x Marquis
(H44 - DC) x Ma.......	1703	1857	Univ. Sask.	(H-44-24 x Double Cross) x Marquis
H44 x Ma....	1743	1876	D. R. R. L.	H-44-24 x Reward
H44 x Rew ..	1735	1856	D. R. R. L.	H-44-24 x Reward
H44 x Rew ..	1738	1875	D. R. R. L.	H-44-24 x Reward
H44 x Rew...	1739	1873	D. R. R. L.	H-44-24 x Reward
H44 x Rew...	1740	1872	D. R. R. L.	H-44-24 x Reward
H44 x Rew ..	1741	1874	D. R. R. L.	H-44-24 x Reward
Hope x Ma...	1748	1865	D. E. S. Br.	Hope x Reward
Hope x Rew..	1736	1853	D. E. S. Br.	Hope x Reward
Hope x Rew	1737	1864	D. E. S. Br.	Hope x Reward
Hope x Rew.	1744	1878	D. R. R. L.	Hope x Reward
Hope x Rew .	1745	1879	D. R. R. L.	Hope x Reward
Hope x Rew.	1746	1863	D. E. S. Br.	Hope x Reward
Huron.......	1252	1344	C. E. F. Ot.	White Fife x Ladoga
Ko. x Ma....	1768	——	N. Dak. E. S.	Kota x Marquis
Marquis.....	7	1397	C. E. F. Ot.	Hard Red Calcutta x Marquis
Marquis.....	70	1404	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis.....	100	1404	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis.....	146	1868	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis.....	151	1869	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis.....	1719	1831	C. E. F. Ot.	Hard Red Calcutta x Marquis
Mindum.....	64	1418	Minn. E. S.	Durum admixture in Hedgerow
Pelissier.....	41	1461	U. S. D. A.	Mediterranean durum
Pelissier	109	1859	Univ. Sask.	Mediterranean durum
Pelissier.....	1135	1860	Univ. Sask.	Mediterranean durum
Pnt. x Ma....	1742	1877	D. R. R. L.	Pentad x Marquis
Reliance.....	1851	1498	U. S. D. A.	Kanred x Marquis
Reward......	1003	1509	C. E. F. Ot.	Marquis x Prelude
Thatcher.....	1720	1820	Minn. E. S.	(Kanred x Marquis) x (Marquis x Iumillo)

TABLE I.—*Continued.*

Variety	Univ. of Sask. Accession No.	Canadian Accession No.	Source*	Origin
			Barley	
Club Mariout	2073	729	U. S. D. A.	Introduced from North Africa
Colsess	1636	772	Colo. E. S.	Success x Coast
Comfort	1698	1107	Minn. E. S.	(Lion x Manchuria) x Manchuria
Glabron	1699	1093	Minn. E. S.	(Lion x Manchuria) x Luth
Hannchen	229	1109	Svalof	
Mens. x Lion	1769	1105	C. E. F. Ot.	Mensury Ott. 60 x Lion
Newal	1726	1089	Univ. Alta.	Manchuria-Lion x O. A. C. 21
Nobarb	1730	1022	O. A. C.	O. A. C. 21 x Lion
O. A. C. 21	228	1086	O. A. C.	Selected from Manchuria
Pannier	1770	1042	U. S. D. A.	Introduced from Tibet
Peatland	1721	1112	Minn. E. S.	Selected from Swiss variety
Regal	1865	742	Univ. Sask.	(Lion x Manchuria) x Manchuria
Sanalta	1731	1088	Univ. Alta.	Smooth Awn x Duckbill
Sansbarb 2	1722	1074	D. E. F. S. C.	Albert x Lion (N. C.)
Sansbarb 3	2062	746	D. E. F. S. C.	Junior x Lion (N. C.)
Sol	1667	782	Univ. Sask.	Selected from Sixty Day
Trebi	101	1108	U. S. D. A.	Introduced from North Africa
V. H. 9	1752	——	Univ. Sask.	Velvet x Hannchen
V. H. 13	1753	——	Univ. Sask.	Velvet x Hannchen
V. H. 19	1754	——	Univ. Sask.	Velvet x Hannchen
V. H. 70	1755	——	Univ. Sask.	Velvet x Hannchen
V. H. 105	1756	——	Univ. Sask.	Velvet x Hannchen
V. H. 149	1757	——	Univ. Sask.	Velvet x Hannchen
V. H. 151	1758	——	Univ. Sask.	Velvet x Hannchen
V. H. 153	1759	——	Univ. Sask.	Velvet x Hannchen
V. H. 264	1760	——	Univ. Sask.	Velvet x Hannchen
V. H. 266	1761	——	Univ. Sask.	Velvet x Hannchen
Velvet	1239	1102	Minn. E. S.	(Lion x Manchuria) x Luth
Vel. x Char.	1734	1110	D. E. F. Br.	Velvet x Charlottetown 80
Vel. x Mens.	1732	1106	D. E. F. Br.	Velvet x Mensury Ott. 60
Wis. Ped. 38	2069	1101	Wis. E. S.	Lion x Manchuria
			Oats	
Anthony	2001	216	Minn. E. S.	Victory x White Russian
Banner	144	11	C. E. F. Ot.	Introduced from Europe
D. C. Sel.	1762	——	S. Dak. E. S.	
Gopher	1284	14	Minn. E. S.	Selected from Sixty Day
Hyb. 117	1763	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 121	1764	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 123	1765	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 132	1766	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 137	1767	——	Ohio E. S.	Red Rust Proof x Hulless
Rusota	1724	327	N. D. E. S.	Selected from Green Russian
S-200	1733	646	D. E. F. Br.	
Victory	145	426	C. E. F. Ot.	Selected from Probsteier
			Flax	
Bison	2041	2100	N. D. E. S.	Selected from common seed flax
Crown	272	2109	N. D. E. S.	Selected from common seed flax
W. R. 28	1727	——	Univ. Sask.	Selected from Crown

*Abbreviations: Univ. Sask.—University of Saskatchewan, Saskatoon, Sask.; D.E.F.— Dominion Experimental Farm; Br.—Brandon, Manitoba; U.S.D.A.—United States Department of Agriculture; Univ. Alta.—University of Alberta, Edmonton, Alberta; N. Dak. E. S.—North Dakota Agricultural Experiment Station; Fargo, N. Dak.; C. E. F. Ot.—Central Experimental Farm, Ottawa; D. R. R. L.—Dominion Rust Research Laboratory, Winnipeg, Man.; Minn. E.S.—Minnesota Agricultural Experiment Station, St. Paul, Minn., U. S. A.; Ohio E. S.—Ohio Agricultural Experiment Station, Wooster, Ohio; Colo. E. S.—Colorado Agricultural Experiment Station, Fort Collins, Colo.; O. A. C.—Ontario Agricultural College, Guelph, Ontario; D. E. F. S. C.—Dominion Experimental Farm, Swift Current, Sask.; Wis. E. S.—Wisconsin Agricultural Experiment Station, Madison, Wisconsin.

probability curve. The plat arrangements and analyses of data for the comparative rod-row tests were made according to the variance methods outlined by Fisher (1) and elucidated by Snedecor (7). In each test frost data were taken on the first four replicates only.

RESULTS

FORTIETH-ACRE PLATS

The series of 1/40-acre plats contained the leading small grain varieties of western Canada. All of the plats were sown on May 14 and emerged on May 25, 26, and 27. At the time of the frost practically all of the plants were in the two-leaf stage. A study of the data revealed no effects attributable to differences in date of emergence.

This series of plats contained wheat varieties alternated with varieties of oats and barley in an unreplicated sequence. However, as the plats were long and narrow and as the frost results checked closely with those from nurseries where randomized replication was used, it is probable that the results represent fairly accurately the relative frost resistance of the different varieties and crops.

The summarized results are given in Table 2. The last two columns of the table show for each variety its frost resistance rank and the position it actually occupied in the field. A glance down the two columns shows no appreciable relationship between rank and location, consequently the fact that the results are from an unreplicated series need not be considered when studying the data.

Within each of the four crops there appear to be significant differences between varieties. Among the wheats Reliance and Mindum were outstanding and showed almost no frost injury. Thatcher came next in resistance. Marquis, Garnet, Apex, and Pelissier were intermediate, while Reward and Ceres showed the least resistance of all of the varieties.

Among the oat varieties Banner and Victory were the least injured, but the differences among the four varieties were not large.

The barley variety reactions were much more differential. Regal was injured relatively little, whereas Colsess was badly injured. Trebi also was fairly severely injured.

The flax test showed a fairly distinct difference between Crown and Bison, the latter being more severely injured. W. R. 28 reacted somewhat like Crown.

A SERIES OF 1/1000-ACRE PLATS

Further frost data on representative cereal and flax varieties were obtained from the series of 1/1000-acre plats which was situated 1,800 feet from the 1/40-acre plats reported upon in Table 2. The results are summarized in Table 3 and closely resemble those of Table 2, except for the oat varieties where the differences were comparatively small in both nurseries. Reliance wheat, Regal barley, and Crown flax were the least injured varieties and Reward, Ceres, Colsess, and Bison the most injured in their respective crops in both sets of results.

TABLE 2.—*The effect of a spring frost on seedlings of spring-sown cereal crops in a series of fortieth-acre plats.**

Variety	Distribution of samples according to the mean degree of freedom from frost injury of the plants of each sample																			Frost resistance rank	Sowing order by plat no.
	4.8	5.1	5.4	5.7	6.0	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9.0	9.3	9.6	9.9	Mean		
Wheat																					
Reliance	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	3	11	9.8	1	12
Mindum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	5	7	9.7	2	17
Thatcher	–	–	–	–	–	–	–	–	–	–	–	–	2	1	3	3	1	5	9.3	3	19
Garnet	–	–	–	–	–	–	–	1	–	–	–	1	1	2	5	1	2	2	8.9	4	8
Marquis 100	–	–	–	–	–	–	–	–	–	–	2	3	2	4	–	–	4	–	8.7	5	1
Peliss. 109	–	–	–	–	–	–	–	–	1	1	1	4	–	1	4	1	2	–	8.6	6	14
Apex	–	–	–	–	–	–	–	–	–	2	2	2	1	2	4	2	–	–	8.5	7	4
Ceres	–	–	–	–	–	–	–	–	4	2	1	2	3	1	2	–	–	–	8.0	8	10
Reward	–	–	–	–	–	–	1	–	–	3	4	1	3	3	–	–	–	–	8.0	8	6
Oats																					
Banner	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	5	1	6	9.5	1	2
Victory	–	–	–	–	–	–	–	–	–	1	–	–	–	1	2	3	5	3	9.2	2	3
Anthony	–	–	–	–	–	–	–	–	1	–	–	1	4	3	2	1	1	2	8.7	3	5
Gopher	–	–	–	–	–	–	–	–	1	1	1	1	3	3	1	4	–	–	8.6	4	7
Barley																					
Regal	–	–	–	–	–	–	–	–	–	–	2	4	1	2	1	2	2	1	8.7	1	11
O. A. C21	–	–	–	–	–	–	1	2	–	–	3	3	1	1	2	–	–	2	8.2	2	9
Hannchen	–	–	–	–	–	–	1	2	–	2	4	–	3	1	1	1	–	–	7.9	3	15
Trebi	–	–	–	–	–	1	2	2	1	4	2	2	1	–	–	–	–	–	7.4	4	16
Colsess	2	1	–	2	1	1	4	1	1	1	1	–	–	–	–	–	–	–	6.3	5	13
Flax																					
		1.1	1.4	1.7	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	Mean		
Crown		–	–	–	–	–	–	1	1	2	1	–	2	1	2	–	5	–	4.5	1	21
W. R. 28		–	–	–	1	–	–	1	1	–	1	3	–	3	3	1	1	–	4.3	2	20
Bison		1	–	1	2	–	–	–	2	4	–	1	2	1	–	1	–	–	3.4	3	18

*In each sample there were from 10 to 30 plants. Frost injury of individual plants was recorded as 0 if killed to ground and up to 10 for no injury in the case of cereals, and 0 to 6 for flax.

TABLE 3.—*The effect of spring frost on varieties of small grains and flax grown in a series of 1/1000-acre plats.*

Variety	Degree of frost resistance	Frost resistance rank
	Wheat	
Reliance	9.2	1
Garnet	8.2	2
Marquis 100	7.0	3
Reward	6.6	4
Ceres	6.4	5
	Oats	
Gopher	9.8	1
Victory	9.4	2
Banner	7.9	3
	Barley	
Regal	9.2	1
Hannchen	8 9	2
O. A. C. 21	8.8	3
Trebi	8.1	4
Colsess	5.4	5
	Flax	
Crown	5.0	1
Premost	3.8	2
Bison	3.2	3

Substantiation of the principal differences in these tests was found in other places. For example, the Colsess on University Seed Farm was killed almost down to the ground while a nearby field of Regal was only moderately injured. Again, the Marquis on University Seed Farm was badly injured, but Reliance was barely touched by the frost.

REPLICATED ROD-ROW PLAT TESTS OF WHEAT VARIETIES

The rod-row plat tests of small grains were situated approximately 800 feet from the fortieth-acre plats and experienced more severe frost damage than the latter. The test of new rust resistant wheats was sown on May 9 and emerged on May 21 and 22. The results from four replicates are given in Table 4. The other test was a six replicate triple rod-row plat test of various common and durum varieties many of which were also in the foregoing test. The test of durum and common wheats was sown on May 10 and emerged on May 22. The summarized results from four replicates are presented in Table 5. The two tests were adjacent, the former being slightly nearer to the fortieth-acre plats.

The variance analysis of the results from the test of rust resistant wheats revealed highly significant differences between varieties as described at the foot of Table 4. The actual data from each of the four replicates are given in the table to show the consistency of the results. Canus, a variety from the cross Kanred winter wheat x Marquis, was only slightly injured and appeared to be significantly

TABLE 4.—*Resistance to spring frost injury in a test of 25 varieties of common wheat.*

Variety or hybrid	Sask. Acces. No.	Index of frost injury: Repl. 1	Repl. 2	Repl. 3	Repl. 4	Mean and SE*	Frost resistance rank
Canus	1725	9	7	8	9	8.3 ±.90	1
Thatcher	1720	5	5	7	6	5.6 ±.61	2
Early Triumph	603	6	4	7	5	5.5 ±.60	3
Garnet	791	7	3	4	7	5.3 ±.57	4
Huron	1252	6	4	4	6	5.0 ±.54	5
Hope x Marquis	1748	4	4	4	5	4.3 ±.46	6
H-44-24 x Reward	1739	6	3	3	5	4.3 ±.46	6
H-44-24 x Reward	1743	6	3	4	4	4.3 ±.46	6
Marquis	1719	6	2	4	4	4.0 ±.43	7
Reliance x Hope	1751	4	3	4	5	4.0 ±.43	7
(H-44 x Doub Cr.) x Marq	1703	4	3	3	5	3.8 ±.41	8
(H-44 x Doub. Cr.) x Marq	1702	5	2	5	3	3.8 ±.41	8
Ceres	1212	6	2	4	3	3.8 ±.41	8
Pentad x Marquis	1742	4	3	4	4	3.8 ±.41	8
(H-44 x Doub. Cr.) x Marq	1701	5	2	3	4	3.5 ±.38	9
H-44-24 x Reward	1741	3	4	3	4	3.5 ±.38	9
Hope x Reward	1745	4	3	3	4	3.5 ±.38	9
Hope x Reward	1737	4	3	3	3	3.3 ±.35	10
Hope x Reward	1736	3	3	4	3	3.3 ±.35	10
Reward	1003	3	2	3	4	3.0 ±.33	11
H-44-24 x Reward	1735	3	3	3	3	3.0 ±.33	11
H-44-24 x Reward	1740	5	2	2	3	3.0 ±.33	11
H-44-24 x Reward	1738	3	3	3	3	3.0 ±.33	11
Hope x Reward	1746	2	2	3	4	2.8 ±.30	12
Hope x Reward	1744	3	1	3	3	2.5 ±.27	13

*The variety variance divided by the error variance gave F = 8.0. The 1% point = 2.07. The standard error of the mean index of injury of a variety [S.E.y] = 10.9%. The odds are more than 20 : 1 that varieties below the solid line were more injured than Thatcher and that varieties below the dotted line were more injured than Marquis.

more frost resistant than any of the other varieties in the test. Thatcher, a new hybrid variety, was next highest in frost resistance and appeared significantly less injured than Marquis or Ceres and very significantly less injured than Reward. Most of the new hybrid varieties were significantly more injured than Thatcher, Early Triumph, and Garnet.

Highly significant varietal differences were found also in the frost results presented in Table 5. Mindum, Canus, and Reliance were high in frost resistance. All varieties below Reliance appeared to be significantly more injured than Mindum, as shown by the star and bar in the first column after the standard errors. Ceres and Marquis were intermediate in frost injury and Reward was one of the most susceptible varieties.

TABLE 5.—*Resistance to spring frost injury in a quadruplicate randomized rod-row plat test of 24 varieties of durum and common wheat.*

Variety or hybrid	Univ. Sask. Acc. No	Frost injury index and SE*	The odds are more than 20:1 that the variety starred was less injured than any below the lower bar and more injured than any above the upper bar in the same column					Frost resistance rank
Mindum	64	9.3 ±.72	*					1
Canus	1725	9.0 ±.69						2
Reliance	1851	8.5 ±.65			—			3
Golden Ball	1887	7.5 ±.58						4
Pelissier	41	7.5 ±.58		*				4
Thatcher	1720	7.5 ±.58	—			—		4
Pelissier	109	7.0 ±.54						5
Pelissier	1135	6.3 ±.49						6
Hope x Ceres	1750	6.0 ±.46					—	7
Garnet	791	5.8 ±.45		—	*			8
Hope x Reward	1737	5.5 ±.42						9
(H-44-DC) x Ma	1702	5.3 ±.41						10
Ceres	1212	5.3 ±.41						10
Marquis	7	5.3 ±.41						10
Marquis	100	5.3 ±.41				*		10
(H- 44-DC) x Ma	1701	5.0 ±.39						11
(H- 44-DC) x Ma	1703	5.0 ±.39						11
Marquis	70	5.0 ±.39						11
Marquis	146	4.8 ±.37						12
Marquis	151	4.5 ±.35			—		*	13
Marquis	1719	4.3 ±.33						14
Reward	1003	4.3 ±.33						14
H- 44 x Reward	1735	4.3 ±.33				—		14
Kota x Marquis	1768	3.8 ±.29						15

*F value for variety variance divided by error variance = 21.7. The 1% point = 2.07. SE_V = 7.7%.

Eleven varieties were in both tests. The frost resistance rank of these varieties in Table 4 is 1, 2, 4, 7, 8, 8, 8, 9, 10, 11, 11, and in Table 5 it is 2, 4, 8, 10, 11, 10, 10, 11, 9, 14, 14. Except that Sask. 1703 and Sask. 1737 are not in the same relative positions in the two tables, the agreement between the results of the two tests is excellent. It is of interest to note in Table 5 that the four durum varieties ranked high in frost resistance whereas all of the Marquis strains were in the lower half of the list. It is also of interest that Garnet appeared significantly less injured than Reward in both tests.

The results presented in Tables 2, 3, 4, and 5 demonstrate clearly that both the standard wheat varieties and the new hybrid varieties differed very significantly in the amount of injury they sustained as a result of the June frost. The rank of the different varieties with respect to frost injury was surprisingly consistent in the three experiments. Reliance, Canus, and Mindum in each case took first, second, or third place. Reward and some of the new hybrid wheats were

correspondingly at or near the bottom. Marquis strains assumed intermediate positions along with Ceres and Garnet.

REPLICATED ROD-ROW PLAT TESTS OF BARLEY

The test of smooth-awned barley varieties was grown less than 200 feet from the fortieth-acre plats reported on in Table 2. The seeding was done on May 14 and emergence took place on May 23 and 24. The summarized results on frost injury in four of the replicates are given in Table 6. Glabron, Regal, Comfort, and Velvet, all hybrid varieties of similar parentage, proved the most frost resistant. Hannchen, O.A.C. 21, and Trebi, three standard varieties of western Canada, appeared to be significantly more injured than Glabron. Five of the newest smooth-awned barleys were at the bottom of the list being significantly more injured than Hannchen.

TABLE 6.—*Resistance to spring frost injury in a four replicate randomized rod-row plat test of 16 barley varieties.*

Variety	Frost injury index and SE*		Frost resistance rank
Glabron	8.8	±.63	1
Comfort	8.5	±.61	2
Velvet	8.3	±.59	3
Regal	8.3	±.59	3
Hannchen	7.0	±.50	4
O. A. C. 21	6.8	±.48	5
Trebi	6.3	±.45	6
Mens. x Lion	6.0	±.43	7
Wis. Ped. 38	6.0	±.43	7
Vel. x Char	5.8	±.41	8
Sanalta	5.8	±.41	8
Newal	5.5	±.39	9
Vel. x Mens	5.5	±.39	9
S. B. 2	5.3	±.38	10
Nobarb	4.5	±.32	11
S. B. 3	4.3	±.31	12

*F value for variety variance divided by error variance = 9.6. 1% point = 2.7. SE_V = 7.1%. The odds are more than 20 : 1 that varieties below the solid line were more injured than Glabron and that varieties below the dotted line were more injured than Hannchen.

The summarized results from the test of standard barley varieties and new smooth awned hybrids are shown in Table 7. This test was situated about 150 feet from the wheat test reported in Table 5. It was sown on May 15 and emergence occurred on May 24 with a few plats on May 25 and 26. The figures on the standard varieties Regal, Hannchen, Trebi, O. A. C. 21, and Colsess agree closely with the results given in Tables 2, 3, and 6. Four of the Velvet Hannchen lines ranked close to Hannchen and Regal, while five of the others were more frost injured than Regal by odds of more than 21 : 1. However, the least frost resistant of the Velvet Hannchen lines appeared to be significantly more resistant than Colsess, Peatland, Club Mariout, Sol, and Sansbarb 2.

TABLE 7.—*Resistance to spring frost injury in four replicates of a randomized rod-row plat test of 20 barley varieties.*

Variety	Frost injury index and SE*	Frost resistance rank	The odds are more than 20:1 that the variety starred was less injured than any below the lower bar and more injured than any above the upper bar in the same column			
VH 266	9.5 ±.58	1	*			
Regal	9.3 ±.57	2				
VH 9	9.0 ±.55	3				
VH 70	9.0 ±.55	3				
Hannchen	8.5 ±.52	4				
VH 153	8.5 ±.52	4		*		
O. A. C. 21	8.3 ±.51	5				
VH 149	8.3 ±.51	5				
VH 19	7.8 ±.48	6				
VH 264	7.8 ±.48	6				
VH 151	7.8 ±.48	6	—		*	
VH 13	7.3 ±.45	7				
VH 105	7.0 ±.43	8				—
Pannier	6.8 ±.42	9		—	—	
Trebi	6.0 ±.37	10				
Sans Barb 2	5.5 ±.34	11				*
Sol	5.3 ±.32	12				
Peatland	4.8 ±.29	13				—
Colsess	4.0 ±.24	14				
Club Mariout	3.3 ±.20	15				

*F value for variety variance divided by error variance = 16.9. 1% point = 2.5. SE_V = 6 1%

REPLICATED ROD-ROW PLAT TEST OF OAT VARIETIES

The test of oat varieties was adjacent to the barley test reported in Table 7. The test was sown on May 17 and emerged mostly on May 27 with some plats on May 26 and 28. The frost notes are reported

TABLE 8.—*Resistance to spring frost injury in a four replicate rod-row plat test of 12 oat varieties.*

Variety	Frost injury index and SE*	Frost resistance rank
Victory	9.0 ±.47	1
Gopher	8.8 ±.46	2
Anthony	8.8 ±.46	2
Rusota	8.8 ±.46	2
Banner	8.5 ±.45	3
D. C. Sel.	8.5 ±.45	3
Hyb. 123	8.0 ±.42	4
Hyb. 117	8.0 ±.42	4
Hyb. 121	8.0 ±.42	4
Hyb. 132	7.8 ±.41	5
....	....	....
Hyb. 137	7.0 ±.37	6
S.—200	4.8 ±.25	7

*F value for variety variance divided by error variance = 7 6. 1% point = 2.74. SE_V = 5.3%. The odds are more than 40:1 that varieties below the dotted line were more injured than Victory.

in summarized form in Table 8. Among the varieties Victory, Gopher, Anthony, and Rusota were the least injured. Banner and D. C. Selection were next. None of the Ohio hybrids were as resistant as the standard varieties and as a group they were significantly more injured than the four varieties of highest rank. One variety, S. 200, was much more injured than any other variety in the test.

DISCUSSION

ECONOMIC IMPORTANCE OF FROST RESISTANCE

Cool growing conditions are best for wheat, oats, and barley in the early growth stages, but when these cereals are sown in western Canada early enough in the spring to have such conditions there is a fair likelihood that the temperature will sink below 32° once, and perhaps more than once, after the crop is up. Frost damage to seedling wheat has been shown by Waldron (10, 11) to have an adverse effect on the height and grain yield of the crop. It is probable that frost damage to seedling barley and oats likewise has a detrimental effect on yield.[4] In the case of flax it is well known that frost in the seedling stage may damage the crop extensively. It appears that for western Canada and the adjacent plains region of the United States there is a definite need for as high a degree as possible of seedling resistance to frost injury in the varieties in general use.

VARIETAL DIFFERENCES

In the present study highly significant differences in frost injury were found among the wheat, oat, barley, and flax varieties commonly grown in western Canada. Recent literature shows that such differences may be expected. Harlan and Shaw (2) tested a number of barley varieties for frost resistance at high altitudes in Idaho and found large differences in resistance, some varieties from high altitudes in Asia being far more cold resistant than most of the other varieties. McFadden (4) mentioned in 1930 that Hope wheat was more susceptible to frost than most other hard red spring wheats. Martin (5), in his cold resistance study of spring wheats, also found large differences between varieties. Peltier and Kiesselbach (6), using artificial refrigeration in Nebraska, obtained highly significant differences in cold resistance within each of the spring-sown crops of wheat, oats, and barley.

CONSISTENCY OF VARIETAL DIFFERENCES

The data in the present study were secured under natural field conditions from several different experiments situated hundreds of feet apart, yet the results are markedly consistent. This consistency is best seen when the rankings of the standard varieties are brought together from the various tables. In Table 9 the rankings are given for all varieties which appear in two or more of Tables 2 to 8.

This tabulation demonstrates that the amount of seedling frost injury in a given variety in one nursery was a good indication of

[4]Results which confirm this view have been obtained at Saskatoon and are to be published soon.

TABLE 9.—*Consistency of varietal differences.*

Variety	Table number							Average
	2	3	4	5	6	7	8	
				Wheat				
Reliance	1	1	–	1	–	–	–	1.0
Garnet	2	2	1	2	–	–	–	1.8
Marquis	3	3	2	4	–	–	–	3.0
Ceres	4	5	3	3	–	–	–	3.8
Reward	4	4	4	5	–	–	–	4.2
				Barley				
Regal	1	1	–	–	1	1	–	1.0
Hannchen	3	2	–	–	2	2	–	2.2
O. A. C. 21	2	3	–	–	3	3	–	2.8
Trebi	4	4	–	–	4	4	–	4.0
Colsess	5	5	–	–	–	5	–	5.0
				Oats				
Victory	2	2	–	–	–	–	1	1.7
Gopher	3	1	–	–	–	–	2	2.0
Banner	1	3	–	–	–	–	3	2.3
				Flax				
Crown	1	1	–	–	–	–	–	1.0
Bison	2	2	–	–	–	–	–	2.0

the amount in the same variety in other nurseries. In oats, Banner and Gopher changed places in Tables 2 and 3, but the differences between the varieties were relatively small.

It is of interest that the results obtained by Peltier and Kiesselbach (6) under artificial refrigeration in Nebraska are in close agreement with the data given here with respect to the varieties that were tested at both Lincoln, Nebr., and Saskatoon, Sask. These varieties are Glabron and Trebi barley and Ceres, Garnet, and Marquis wheat.

GEOGRAPHICAL ANCESTRAL INFLUENCES

Throughout the frost injury data there appears to be a relationship between remote ancestry and susceptibility to frost damage. That is, on the whole, varieties coming from warm regions of the earth or having part of their inheritance from such regions appear to have suffered more frost damage than those coming from cold regions. This is especially noticeable in the case of wheat and warrants a close inspection of ancestral influences.

It is particularly interesting that the wheat varieties possessing inheritance from the hardy winter wheat Kanred showed more frost resistance than the other bread wheats, and that those having emmer and Indian inheritance were as a group distinctly less resistant than the others. The durums also differed, the two warm-country varieties being less frost resistant than Mindum whose ancestors probably came from Russia.

Table 10 shows the frost results groups roughly according to the influence of origin.

TABLE 10.—*Effect of varietal origin on frost resistance.*

Varieties	Information origin	Table number				Average for Tables 4 and 5
		2	3	4	5	
Mindum..................	Cold climate durum	9.7	—	—	9.3	—
Reliance, Canus............	Half Kanred	9.8	9.2	8.3	8.8	8.6
Thatcher	Quarter Kanred	9.3	—	5.6	7.5	6.7
Peliss., Golden Ball..........	Warm climate durum	8.6	—	—	6.9	—
(H-44-DC) x Ma. Hybrids....	Sixteenth Kanred nearly half Indian	8.5	—	3.8	5.1	4.5
Marquis...............	Half Indian	8.7	7.0	4.0	4.9	4.2
H-44 x Rew. (C. A. N. 1856) and Hope x Rew. (C. A. N. 1864)	Quarter emmer nearly half Indian	—	—	3.2	4.9	4.1
Reward	Over half Indian	8.0	6.6	3.0	4.3	3.7

Consideration of these results leads to greater emphasis on the influence of origin when planning a breeding program. It is generally recognized that many different character combinations may be obtained by crossing two varieties of diverse origins; and it is well understood that the parental varieties bring with them both favorable and unfavorable characters which may be retained or rejected as desired in the hybrid progeny. But is it as well understood that characters which are not of particular interest for the immediate solution of the problem in hand and which therefore may be ignored or not noticed are nevertheless present in the progeny and may be of considerable importance under a given set of environmental conditions?

SUMMARY

1. On June 4, 1935, a widespread frost occurred at Saskatoon, Sask., and caught most of the cereal breeding and testing nurseries when the seedlings were in the critical two-leaf stage.

2. Highly significant differences in frost injury were found among the wheat, oat, barley and flax varieties commonly grown in western Canada as well as in the new hybrid varieties. Some varieties were badly injured while others showed high degrees of frost resistance.

3. The results in different nurseries, even where they were a thousand feet apart, were very consistent.

4. Frost susceptibility was particularly noticeable in varieties having a large amount of warm-climate ancestry, whereas varieties having mostly cold-climate ancestors were frost resisting.

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SELECTION OF OPEN-POLLINATED TIMOTHY[1]

MORGAN W. EVANS[2]

COOPERATIVE timothy breeding investigations have been conducted at the Timothy Breeding Station, at North Ridgeville, Ohio, for a number of years. Although the primary purpose of these investigations has been the development of new varieties of timothy (*Phleum pratense* L.), incidental studies have been made of the variations which occur and of the extent to which these variations have been transmitted from one generation to another when selected plants have been propagated by seeds produced under natural conditions with no provision for self-pollination. Timothy is largely cross-pollinated under natural conditions, although on some plants a fair set of seed may be obtained by self-pollination (3, 7).[3]

The fact that numerous variations occur has been observed for many years (4, 5, 6). The plants in any field of common timothy vary as to length of stem, earliness or lateness, length of time during which the leaves remain green, and in other ways.

MATERIALS AND METHODS

Plants of timothy selected from meadows, roadsides, and elsewhere comprised original material. These plants were selected for various characteristics, as size or vigor of the plant, length of stems, earliness or lateness, freedom from rust, and tendency for the leaves to remain green as the seeds approached maturity.

The selected plants were grown in a nursery with no attempt to prevent cross-pollination. Seed from selected plants was sown in a bed during the autumn and from 16 to 25 progeny plants transplanted either in late summer or early autumn of the following year.

COMPARATIVE UNIFORMITY OF PLANTS PROPAGATED VEGETATIVELY AND GROWN FROM SEED

Fig. 1 after Evans (2) shows the greater uniformity of the plants grown from seed produced by the original selected plant of Huron timothy (F. C. 3937)[4] in comparison with plants from seed of ordinary unselected timothy.

In check plats of ordinary timothy grown in different series during the years 1929 to 1933, the average of the maximum percentage of plants in full bloom was 72.3. The time during which the plants were in bloom in any one plat was usually approximately 3 weeks, and the maximum percentage of plants in full bloom was not very high. In contrast to this, plants propagated vegetatively from a single plant were very uniform. In 90% of the plats of vegetatively propagated plants, all of the plants in each plat were in full bloom on the same date.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating with the Department of Agronomy of the Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication March 4, 1936.

[2]Associate Agronomist, U. S. Dept. of Agriculture.

[3]Reference by number is to "Literature Cited", p 393.

[4]Accession number of the Division of Forage Crops and Diseases.

FIG. 1.—*Left*, six plants of ordinary commercial timothy; *right*, six plants grown from seed produced by the original plant of Huron timothy.

Although never so uniform as plants propagated vegetatively, occasionally all, and more frequently 80 to 90%, of the plants in a plat grown from seed of selected strains were in bloom at one time. This is illustrated in Fig. 2 showing the relative dates of blooming in 1933 of ordinary timothy and of an early variety propagated vegetatively and from seed. The plants from seed bloomed but 2 days later than those propagated vegetatively, which were 9 days earlier than ordinary timothy. Although a slight retrogression occurred, the earliness characteristic of the original plant persisted in the plants grown from its seed to a very large degree (2).

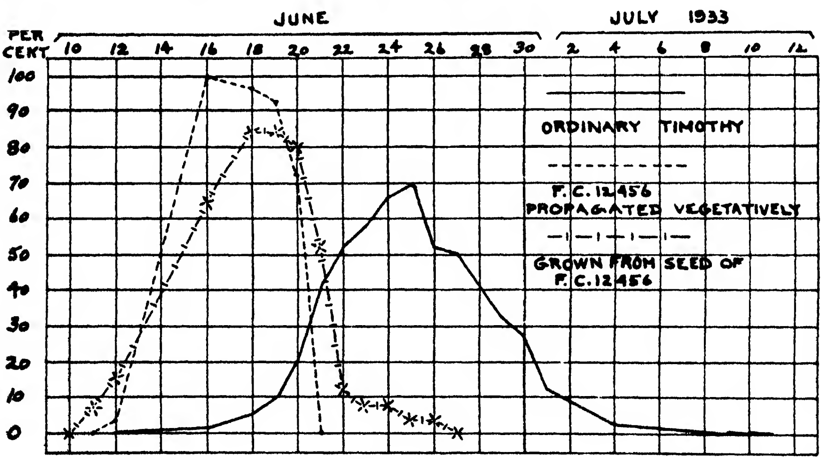

FIG. 2.—Percentage of plants in full bloom of ordinary timothy; of plants propagated vegetatively from the original plant of an early maturing selection; and of plants grown from seed produced by the original plant.

SELECTION FOR LENGTH OF STEMS

Records were taken in 1933 of the length of stem of each plant in a series of 64 plats, 32 of which had been propagated vegetatively from selected individual plants and 32 grown from seed produced by the same original plants. In obtaining the length of stem, the longest stem of each plant was measured from the surface of the soil to the tip of the head.

In the same series were four check plats of ordinary timothy in which the length of stem of all plants averaged 40.2 inches. In only two selections were the average lengths less than those of the checks, and in these the differences were hardly significant. In the five selections having the longest stems the average length of stem of the vegetatively propagated plants was 52.13 inches. The average length of the stem of the plants grown from seeds of these long-stemmed selections was 47.23 inches, or 4.9 inches less than that of the plants propagated vegetatively from the original plants, but 7.0 inches more than that of plants of ordinary timothy. Thus, the plants grown from seed from the five selections having exceptionally long stems, also had long stems. Despite conditions favorable for cross-pollination, the characteristic of long stems is evident to a very large degree in the plants grown from seed for one generation.

SELECTION FOR EARLINESS AND LATENESS

Five pairs were selected in 1917, each pair representing an early and a late selection from a plat grown from seed from a single original plant. Seed harvested from each selected plant was sown in a bed and seedlings were later transplanted to a row plat. In 1922, one of the earliest plants from each early selection and one of the latest plants from each late selection were again selected. Since 1922, selections have been made twice in a similar manner from each early and from each late strain, making a total of four successive generations of selections for earliness and for lateness. The original plants of all generations were retained and seed was again harvested from each. Seedlings of each selection were transplanted to a row plat. In the same series of plats, plants propagated vegetatively and also plants grown from the seed of the original plants from which the first selections were made in 1917 were also grown. In 1929, records were obtained of the dates when the plants in all of these plats were in full bloom.

A timothy head is referred to as being in full bloom when florets are in bloom on two-thirds or more of its length, a plant when 25% or more of the heads are in full bloom and 25% or more additional heads have some florets in bloom and a plat when 50% or more of the heads are in full bloom (1).

A gradual increase in earliness had occurred from one generation to another in the early selections and a corresponding increase in lateness in the late selections. In the third generation, the first for which pairs of selections which had been selected for earliness and lateness were represented, an average difference of 5 days occurred between the early and the late selection, in the fourth generation 9 days, in the fifth generation 13 days, and in the sixth generation a difference of 15 days between the dates maximum percentages of plants were in bloom in the early and late selections. The trends in earliness and lateness continued throughout the course of the experiment, though the increase in spread was somewhat less in the sixth than in the three preceding generations. This is shown graphically in Fig. 3.

Fig. 4 shows the difference in time of blooming of an early and of a late selection both of which were derived four generations earlier from the same original plant.

Within a very few generations both early and late strains have been developed. Progress was more rapid in the earlier generations of selection owing to greater heterozygosity.

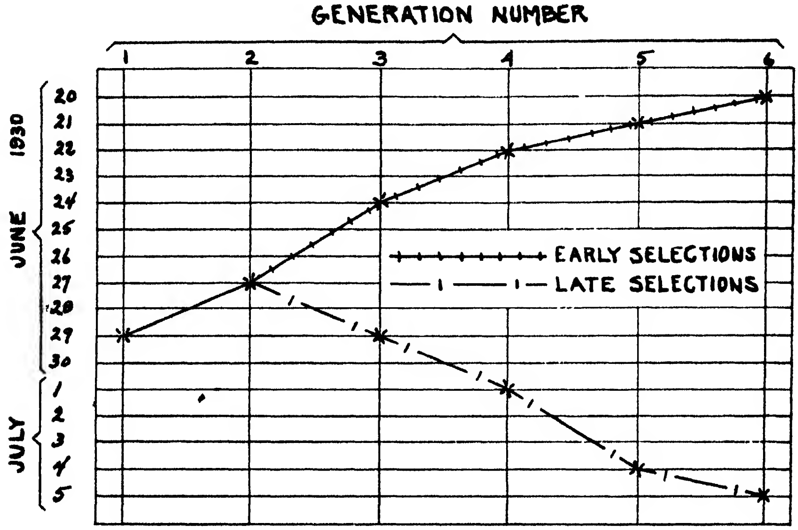

FIG. 3.—Average dates when the maximum percentages of timothy plants were in full bloom in plats of the third, fourth, fifth, and sixth generations selected for either earliness or lateness from six original selections.

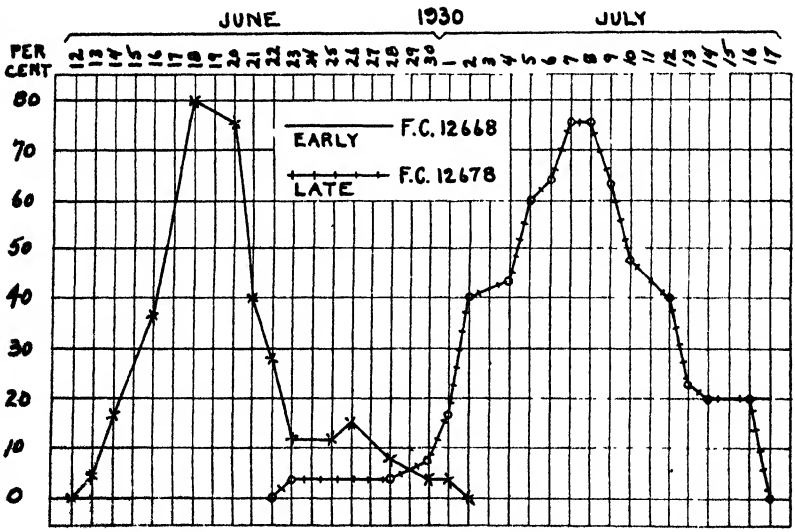

FIG. 4.—Percentage of timothy plants in full bloom on different dates in two plats after the fourth generation of selection for earliness and lateness from the same original plant.

SELECTION FOR GREEN LEAVES

In several seasons, estimates were made of the relative amount of green color remaining in the stems, leaves, and heads of the plants growing in broadcast plats of the late selections, when the ordinary timothy had nearly mature seed. The estimates were the averages of the ratings of several observers, using a scale ranging from 20 for ordinary timothy to 1 for plats in which all stems, leaves, and heads were dark green. In all late selections there were more green leaves and heads than in plats of ordinary timothy.

Table 1 shows the progress through four generations of developing strains which retain their leaves in a green condition comparatively late in the season. The first of this series, Huron timothy, each year has been rated considerably greener than ordinary timothy. In each successive generation the stems, leaves, and heads of the plants have been somewhat greener than in the preceding generation. This tendency to greenness has been correlated to a considerable extent with a gradually increasing lateness in the blooming and maturing of the seed. It has been shown (1) previously, however, that strains of timothy which bloom and mature together may differ in the percentage of green leaves.

TABLE 1.—*Relative rating for green color of unselected timothy and that selected for green leaves.*

Generations of selections	Rating for green color*		Average
	1931	1932	
Unselected	20.0	20.0	20.0
1st generation (Huron timothy)	16.8	14.7	15.7
2nd generation	14.5	14.3	14.4
3rd generation	13.1	13.7	13.4
4th generation	—	13.0	13.0

*A low rating signifies a high intensity of green color

SUMMARY

The high variability in commercial timothy has made possible by continuous selection through several generations the development of strains having longer stems, earlier or later maturity, and better retention of green color in the leaves than the plants from which they were derived. The plants of many of these new strains show a high degree of uniformity, even though grown under natural conditions permitting open pollination.

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SMALL-GRAIN NURSERY EQUIPMENT[1]

HUBERT M. BROWN AND J. W. THAYER, JR.[2]

CHANGES in the size, shape, arrangement, and replication of small plats have necessitated changes in the methods used in the planting, harvesting, and threshing of the grain grown on such plats. Features of five machines now in use on the plant breeding plats at East Lansing and developed under a cooperative project between the sections of Farm Crops and Agricultural Engineering of the Michigan Agricultural Experiment Station are discussed in this article with the hope that they may be helpful to other workers.

Whenever a change has been made, it has been judged on the basis of (1) maintenance of purity, that is, freedom from mechanical mixture; (2) simplicity of operation; (3) efficient use of man power; (4) simplicity of construction; and (5) increase in speed of operation. The first requirement is the most essential and its importance is recognized by all. The other requirements are making themselves felt more and more as experiments are becoming more extensive and refined and expense is becoming more of a factor in planting, harvesting, and threshing.

MACHINES NOW IN USE

Planter.—Four planters, with force feed, were built in 1930 following some of the suggestions of Wiebe.[3] Three were built with small hoppers and one with a large hopper. The former require only 10 grams of seed to fill each machine so that it will begin to plant and are used for planting single rows or replicated plats of a few rows each. The large-hoppered machine is used for planting larger plats. The gears, shown at the right in Fig. 1, mesh as the head is dropped into place. A lever on the handle, within easy reach of the left hand, enables the head to be raised sufficiently to disengage the gears.

Seeds of wheat, barley, oats, rye, sugar beets, and kidney and pea beans have been planted satisfactorily with these drills. Some idea of the rapidity of planting may be gained from the fact that the 7,000 18-foot rows of the barley and oat nurseries of 1935 were planted in 16 to 17 hours, and the 1935 pea bean nursery of 1,350 30-foot rows was laid off, marked out, and planted in a 9-hour day, using these machines.

Cutter.—The present cutter, a one-wheeled garden tractor, was obtained in 1930. One of its regular attachments was a 39-inch oscillating cutter bar using standard sickle knives. A special hood was built over a modification of this regular bar so that it would allow one or two rows of grain to be cut per trip. Fig. 2 gives a side view of the assembly. Practice in the field proved that oats and barley which were standing well could be cut two rows at a time very nicely,

[1]Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article 255 (n.s.). Published with the approval of the Director. Received for publication February 13, 1936.

[2]Research Assistants in Farm Crops.

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but this procedure could not be followed in wheat due to the height of the grain and the bulkiness of the bundles.

The drawback to the use of this machine is that it requires a 15- to 20- foot space for turning around easily at the end of the row. For most efficient use the machine should have a long traverse of cutting between turn arounds. The sections in the plant breeding field are

FIG. 1.—Hand seeder with head slightly raised.

302 feet across. Whenever possible, the field is laid out so as to allow the cutter to go all the way across the section. When this layout is not possible, a series of plats is cut out by hand to provide turn-around space.

The performance record of this machine is remarkable; its clean, rapid job of cutting, together with the compact, easily-handled bundle produced can be fully appreciated only by one who has seen the machine in operation. A five-man crew operates this cutter, the driver, one or two men to hold grain back in grooves, and the remaining men to take away the cut grain. Approximately 1,300 16-foot rows of wheat or 2,000 16-foot rows of barley or oats can be cut dur-

FIG. 2.—Garden tractor grain nursery cutter.

FIG. 3.—Completing the operation of bagging a bundle with the bagger.

ing a 9-hour day. The rate of cutting is greatly influenced by growth of seeded crop, by lodging, and last, but by no means least, by the ambition and efficiency of the operating crew.

Bagger.—This is a galvanized sheet-metal funnel, Fig. 3, and is used to aid in placing the paper bags (25-pound size, flat bottom type) over the heads of the bundles. If the bundle is small and compact, no bagger is needed, but when large, loose bundles are to be bagged, the funnel is a very great help and speeds up this operation materially. Two men work together to do this operation most efficiently.

Tier.—Since 1926, when rod rows were first introduced at the Michigan Station, tying the individual bundles has been a slow and expensive operation. In 1933, a commercial foot-power tier, Fig. 4, was obtained on trial and it so facilitated the work of tying the wheat, oats, and barley rod-row material that it paid for itself the first season.

The machine does not tie bundles as tightly as a binder because

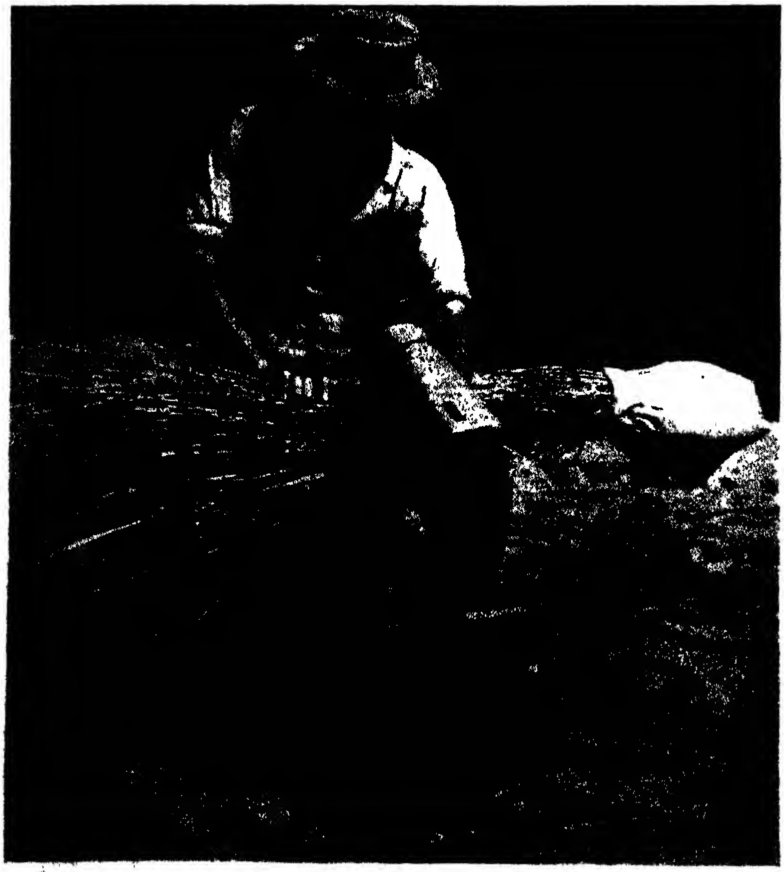

FIG. 4.—Putting the second tie on a grain bundle with the vegetable bunch tier.

there are no packers, other than the operator's hands. However, very little trouble is encountered with the grain slipping out of the ties, if the bundles are handled with reasonable care. This machine can conveniently tie the product from one 16-foot row of barley, oats, rye, or wheat. An 8-ply white cotton twine is used in the machine with a resultant material reduction in twine cost over the use of binder twine.

The crew needed is an operator, and for efficiency, two passers. The passer finishes tucking heads into the bag, pulls the bag as far down over the bundle as possible, squeezes the open end of the bag around the straw, and then passes the bagged bundle to the operator. The first tie is put around the open end of the bag and the second tie around the butt of the bundle. When two or more bundles are tied together, the work must be done by hand.

Nursery thresher.—A description of the several evolutionary stages in the development of this machine would fill many pages and has no place in this article. The easiest way to describe this machine, Fig. 5, is to follow the process through which the grain passes from the time that the bundle is placed on the table until the grain is packed in a carton ready for the laboratory.

The bundle of grain, with the bag string cut and the bag still over the heads, is placed on the table on the right side of the machine (Fig. 6). The butt string of the bundle is not cut unless the entire bundle is to be fed through the cylinder. The feeder takes the bundle from the table and, while the machine is being cleaned of the last variety, checks the number on the bag covering the heads with that on the bag that is to receive the grain. As soon as the machine is clean, the bag is pulled from the bundle and emptied into the hopper. The heads of the bundle are fed directly into the overshot cylinder. Spitting is minimized by having a special baffle of sheet-metal over the top of the cylinder end of the hopper. The baffles do not show in the picture. The grain and straw pass through the cylinder and fall to the bottom of the cylinder chamber where they are picked up by a strong blast of air from the upper fan. The strength of the blast is governed by a damper in the wind conduit between the fan and the cylinder chamber. The damper is set by test before starting plat material so that the strength of the blast will carry the grain and the straw well up into the riddle but will not carry the grain over the end of the riddle. When more air is needed to separate straw from grain in the riddle, it is readily supplied by depressing the lever under the feeder's left foot.

The grain and straw pass out of the cylinder chamber and on to the riddle. The riddle, which was used this year for wheat, rye, barley, and oats, has slits in the bottom, and it is through these slits that the grain, some chaff, and short straws fall. The bulk of the straw remains on top of the riddle and is blown out and over the end of the riddle. The grain and chaff which go through the slits fall onto a smooth piece of sheet-metal down which they slide to the cleaner.

In the cleaner, which has a glass window in either side for purposes of inspection, the grain and chaff fall into an up-draft of air from the lower fan. The grain falls on through into the grain chute and slides

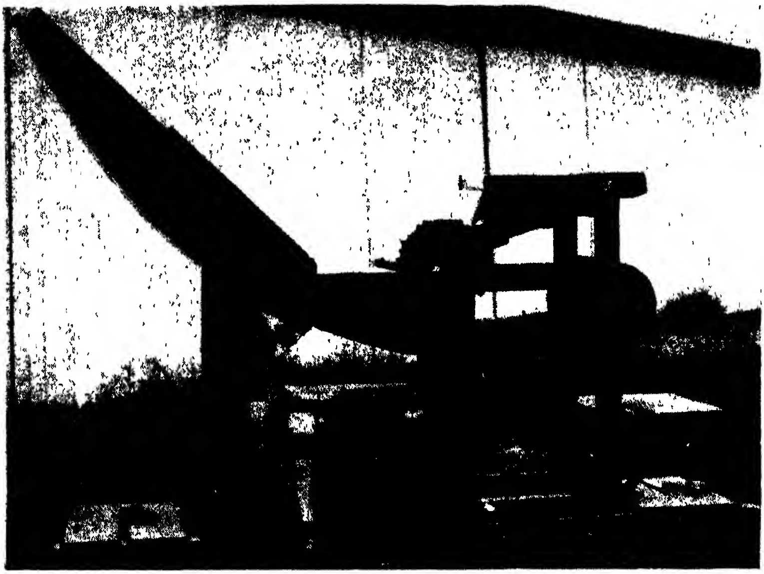

FIG. 5.—Side view of the nursery thresher.

into the envelope, bag, sack, or other container placed for it. The chaff passes on up and out of the cleaner along with the air. The force of the up-draft is regulated by a damper in the wind passage.

The entire machine may be cleaned between varieties in a few seconds by opening the air dampers to their maximum. The end of the grain spout is so fashioned that coin envelopes, 3½ x 5 inches, or

FIG. 6.—View of the nursery thresher in operation.

or 1-pound size paper bags may be as easily slipped over it as the larger sized bags.

This past summer 1,200 3-foot head rows of wheat were individually threshed and bagged in a 9½-hour day. Approximately that number of rod rows of barley, with three rows to a variety, were threshed in a day and the machine cleaned between each variety. Four men make up the crew, one to bring material to the machine, cut ties, and put it up on the table; one to feed, check number, and control the air on the riddle; one to keep the riddle clean; and one to take away the grain and pack it in boxes.

The bags of threshed grain are stacked in order in cartons and taken to the laboratory where they are weighed without further

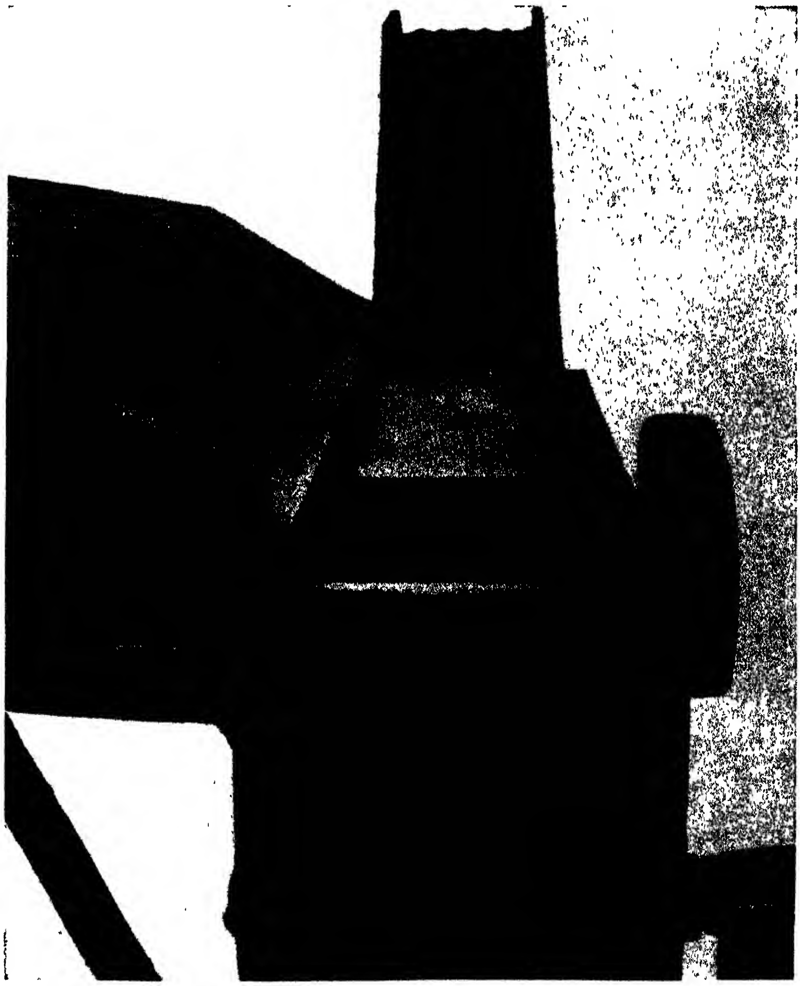

FIG. 7.—Looking at the bean thresher from the feeder's platform.

FIG. 8.—Head or single plant thresher.

cleaning. Samples that are to be used for seed are recleaned so as to remove any pieces of straw that might prevent free running of the grain in the drills.

The grain thresher is quickly converted into a bean thresher by changing cylinder, concave, and riddle and moving the table to the left side of the feed chute. The bean cylinder and concaves have round teeth instead of grain-thresher teeth and the cylinder is rotated much more slowly for threshing beans than it is for threshing grain. The riddle is a piece of corrugated sheet iron with half-inch holes punched in the troughs, Fig. 7. It is possible that this riddle will will work more effectively than the old one for the cereals, but it has not been tried sufficiently to warrant such a statement.

Head or single plant thresher.—The purpose of this machine is to expedite the tedious process of threshing individual heads or plants of cereals. The head or heads of a plant are fed into the funnel at the bottom of which are two rotating wringer rolls, Fig. 8. Old-style hard rolls are now used but are to be replaced by balloon rolls. These pull the head or heads into the cylinder and at the same time effectively prevent the loss of grain by spitting. The cylinder is of the overshot type and does a very excellent job of threshing. The bottom of the cylinder chamber is smooth and sloped so that it directs the grain and chaff into the cleaner. Here the threshed material falls into an up-draft of air through which the grain falls to the chute and into its container. The chaff is blown out of the upper end of the cleaner by the up-draft of air. The force of the air draft in the cleaner is regulated by slides on the end of the fan housing.

This machine has successfully threshed barley, wheat, oats, and rye and the threshed grain was so thoroughly cleaned that very little hand work was needed to reclean it. The lower end of the grain

chute is so fashioned that coin envelopes may be easily and quickly slipped over it. Two men, feeder and bagger, without crowding themselves and yet allowing plenty of time between samples to preclude mixtures, can thresh more than 2,500 single heads or plants in a 9-hour day.

This small machine has also replaced a much larger machine which was formerly used for preparing barley and oat samples for planting. For this operation it is very fast and 100% effective. One-pound samples may be cleaned at the rate of 50 or more per hour by one man operating the machine. Bulk grain may be cleaned at the rate of 4 bushels or more per hour.

Blueprints and specifications necessary for the construction of any of these machines may be obtained upon request from the Farm Crops Department, Michigan State College, East Lansing, Michigan.

PHOTOGRAPHY IN RELATION TO PASTURE INVESTIGATION IN THE SOIL CONSERVATION SERVICE[1]

R. F. Copple[2]

SINCE its beginning the Soil Conservation Service has attempted to make use of every available means which might aid in awakening the American farmer to the problem of erosion and enlist him voluntarily in a national program to conserve the soil. Not only does the farmer need to be enlisted in this program, but also a large percentage of those who are interested in conservation of our resources.

Not the least important of the *implements* at hand is photography, and the potency of the photograph has been constantly stressed as a means of emphasizing the acute need for action to combat erosion. Where the printed word may be drab and uninteresting, pictures tell a graphic and absorbing story—a story readable at a glance by everyone. Behind each photograph should be a reason for its existence. It should not, like Topsy, "just grow up".

Before a photograph is taken definite plans should be made to save both time and motion. Even with careful planning, however, there are a number of situations which lead a photographer almost to despair. One is unfavorable weather, but even that obstacle can sometimes be partially overcome by proper knowledge of photographic technic.

A number of suggestions are made here for those who use or take photographs. These suggestions do not cover the complete list nor are they expected to meet each particular situation or set-up for the photographer. The illustrations used in this paper are on pasture problems, principally in West Virginia and Ohio.

DEPTH OF FOCUS

One of the most important points to remember is depth of focus. This is accomplished best by stopping down the diaphragm to about 32 or less. This small aperture, of course, necessitates taking a much longer exposure. How long the exposure should be, depends upon the light, the film, and the subject. The value of a photo-electric cell for determining the exposure will be discussed under another section. A longer exposure tends to give clearer detail in the foreground, as well as in the background (Fig. 1).

Wind proves an aggrevation to the photographer because he can do little or nothing about it, except postpone the job, if convenient. In some regions the forenoon frequently has less wind than the afternoon. For objects like grain fields which are continuously in motion, an instantaneous exposure is the only choice. Close-ups of turf can be protected from the wind by circling the area to be photographed with about 15 feet of grass rug which may be 3 to 4 feet high, thus

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Also presented at the annual meeting of the Society, held in Chicago, Ill., December 6, 1935. As given at Chicago, this paper included about 30 slides on pasture management which were used to illustrate many of the points on photography. Received for publication February 21, 1936.

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FIG. 1.—Depth of focus. Here the foreground as well as the distant objects are clearly in focus. Stop down the diaphragm and use a tripod.

temporarily protecting the area from wind while the time exposure is made. The tripod should be used constantly.

SHADOWS AND TIME OF DAY

The time of day when shadows are present is usually the best for photographs. The topography of the region frequently determines when a photograph should be attempted. When there is a bright sun, east and west slopes are usually best in the morning and afternoon, respectively. South slopes usually may be photographed best any time except at noon. The season of the year results in considerable variation in the color and shade of crops. The period when there is the greatest contrast in color will result in the best photographs. Shocked corn gives a good contrast. If the crops are similar in color, a filter may be used to advantage to get contrast.

The position of the photographer in relation to the subject may be used to advantage. Occasionally a shot toward the sunshine may bring out crop contrasts as one crop may give a reflection and be overexposed while another may take normal, and thus result in a separation of the crops. The lens should be protected from the direct rays of the sun at all times. This may be done with the slide or with a metal shade which is constructed to fit over the lens.

On a clear day in woodland, it is almost impossible to eliminate sun spots which filter through a dense foliage. Where detail is desired, especially of the duff, roots, or soil profile, thin clouds are especially useful. Where close-ups are needed of bark characteristics, when the sun is shining directly on the object, take the photograph at a right angle to the sun, thus utilizing shadows to advantage. The time of the exposure should not be based on the brightest nor the darkest part of the subject but on an average as most films have considerable time latitude.

SOIL PROFILES

Soil profiles are usually easier to photograph along road cuts. Slice off the weathered slope down to where the soil is not discolored.

In fields and pastures a pit may be dug about 2 feet wide and 18 inches deep with a moderate slope from the ground surface toward the back. This pit or side of the profile is best if facing the sun in order to make it convenient for the cameraman to shade the profile. The back of the pit should not be vertical but should slant back to permit the camera to shoot straight into the soil profile, and thus be in focus from top to bottom. The swingback on the camera may be used to square up the sides, but this usually is used for buildings. Usually it is desirable to shade the soil pit if possible when the sun is bright. The separation of the soil horizons is made by scratching a furrow between them, as the colors and texture are frequently quite similar and impossible for the camera to separate. An 18-inch ruler is handy to show the depth of the profiles. A steel tape is also convenient for deep profiles.

THE BACKGROUND

Frequently the object to be photographed blends so well with the background that some object is essential in order to get a contrast. An automobile, a man, or other object may be used. Cameras which have a delayed timing device which permits the camerman time to get into the photo have merit. Most photographs need a touch of the human element to give them life, employ contrast, and provide a measuring stick for comparison.

FRAME OF THE PICTURE

An artist is cautious when he selects a frame for his painting. The same care is essential for general views in photography. If possible, utilize a tree trunk, dead limb, or similar objects to serve the purpose (Fig. 2).

FIG. 2.—The frame of the picture is important as shown in this black locust-Kentucky bluegrass pasture. A tree trunk or dead limb can be utilized.

TOPOGRAPHY OR SLOPE

In the Soil Conservation Service we are constantly dealing with slopes and run-off, especially in our land utilization program. For practical purposes we can make use of some common implements to serve our needs. In woodland use a tree trunk at one side of the picture or one located in the distance. For fields use a man, the team at work, a perpendicular stake, camera case, or similar objects to show slope (Fig. 3). All of these should be on the level or same contour as the camera, because a photograph taken up or down hill usually gives ambiguous impressions especially as to the amount of slope (Fig. 3).

FIG. 3.—This 30% slope is shown well by the team and also by the apple tree on the right.

THE PHOTO-ELECTRIC CELL

Through experience considerable accuracy may be developed in regard to the time of exposure and size of aperture necessary for each photograph, however, there are times when we fail completely, usually in the photograph needed most. We are dealing with considerable variation in conditions and especially is this true of soils, light, vegetation, season, and topography. The time of exposure necessary in the regions of the Southwest, such as the Gila and Navajo projects, will likely be different from that in the Aroostok potato area in Maine or the Pullman region in eastern Washington, even though the subject may be quite the same. The photographic equipment used is generally accurate and likewise valuable. It is necessary to make the best use of it as well as of the available time. The photoelectric cell is easy to manipulate, compact, accurate, and does not guess.

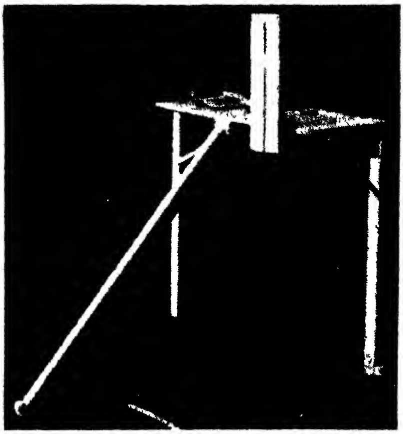

FIG. 4.—A folding table for taking turf photographs in pastures. It is adjustable for height, is economical in cost, and is well adapted for making "retakes" of the same area from year to year.

FILTERS

There are various filters available, but usually if only two or three are used discreetly much better results are to be had. The K2 or yellow filter is best adapted to orthochromatic films. On panchromatic or similar films all filters may be used. The red filter seems to have the widest use, however, it is not satisfactory for films such as orthochromatic which are not sensitive to red. The camera should be focused with the filter attached. The time of exposure will vary according to the type of filter used.

METHODOLOGY

In pasture investigations there are a number of methods used to record the change of turf or vegetation, such as the ocular estimate, the quadrat count and the pantograph. Most of these records are influenced by the personal factor. In many instances it is thought that the photograph may be utilized to eliminate some variations frequently attributed to the recorder.

FIG. 5.—Land use shown on a photograph by inking in the soils and designations. For example, in the foreground the symbol $\frac{M\text{-}P4}{C4}$ is translated as follows: Soil, crop, slope, and erosion with M = Muskingum silt loam; P4 = Pasture with less than 10% desirable species; C = 20 to 30% slope; and 4 = over 75% of the surface soil lost.

11 Swingback 834

PHOTOGRAPHERS B.I.S. J.W.S.

DATE 9/18/35 Green Filter

TIME 9:45 A.M. STOP 32 EXP. 3 sec.

WEATHER CONDITIONS Clear

COM. PAN. LIGHT 100

COUNTY Wirt

TOWN

LONGITUDE 38

LATITUDE 81

DIRECTION AND DISTANCE FROM NEAREST TOWN

1 Mi. S. of Palestine on Highway 14 West of Road

LAND OWNER OR OPERATOR

NAME Isophene Morehead

ADDRESS Palestine, West Va.

REFERENCE TO PERMANENT LAND MARK

Taken S. 20 E. approx. 50 Ft. below 12″ walnut (Blazed)

PHOTOGRAPHER'S POSITION Looking down on lespedeza seeded in contour furrows.

SUBJECT Agronomy

Pasture Management

Contour Furrows

History: Lespedeza was seeded on these contours in March 1935. Note heavy stand obtained. These furrows were also treated with superphosphate and stock naturally grazed the fertilized ridges. When the soil is wet tramping may permit the water to break thru. This may not become serious if the water is caught in the lower furrows. It is recommended that fertilizers be placed between the strips also in order to prevent damage to the furrows.

NOTE: This picture is of no value without exact locations shown.

FIG. 6.—A suggested photograph record.

For turf or close-up studies of vegetation, a folding table has been constructed which is economical, saves time on retakes, and can be adjusted to take vertical phtographs from a height of 36 inches down to 12 inches or closer to the subject (Fig. 4). The area photographed depends upon the height and type of camera, but areas from 20 by 30 inches down to 5 by 7 inches are possible. The changes in vegeta-

tion on the same plat or quadrat may be photographed from year, to year, or more frequently if desired, by using permanent markers.

RECORDS ON THE FILM AND PRINT

The Soil Conservation Service is dealing not only with soil and water conservation but also with better land use. After the soils boundaries have been mapped, we can transfer them on a film for reproduction on a print. The present land use can also be outlined on the film by using opaque ink. We can show on the photograph the present as well as the recommended land use. Opaque ink is more desirable than India ink, as it can be easily removed from the negative if necessary. The ink should be placed on the shiny side of the film (Fig. 5).

THE RECORD

The photograph record is essential. It should be complete. There have been too many photographs taken with incomplete records (Fig. 6). One good photograph is worth a hundred poor ones. However, one may have a good photograph but in order to get the whole story, a "retake" is frequently necessary. To make a "retake", it is essential to go back to the original set-up. Occasionally, it is possible to use the "hunt and fit" system by duplicating the topography, trees, or other permanent land-marks with the original photograph. This is an unnecessary loss of valuable time, even if successful. If the photograph is a "close-up" turf of a terrace outlet or a contour furrow in the pasture, however, the chances are that the original place of the "set-up" will never be located even by the person who made the original photograph, how then does one expect another to find the location without some guide?

Locate the "set-up" with a permanent marker if possible. A rock mound, an iron stake, a conspicuous tree which is blazed, a bridge, a building, a fence corner, or similar marker. Occasionally these may be moved, but they are usually permanent. Wooden stakes usually rot off near the ground. An iron stake is more permanent, but if driven in a meadow where the mower may be broken, future relationships with the farmer may be strained. Then it is essential to take a record of direction with a compass and pace the distance to some permanent landmark. A "repeat" photograph after all is a pictorial barometer of the success of our work. A good picture requires time and patience, but it is worth it.

THE USE OF RAPID SOIL TESTS IN THE UNITED STATES[1]

R. P. THOMAS[2]

A QUESTIONNAIRE pertaining to the use of rapid soil tests was prepared by the Sub-committee on Soil Testing of the general Committee on Fertilizers. Copies of this were sent to the deans of the agricultural colleges and to the experiment station and extension directors in each state, with the request that they be placed in the hands of all who were concerned with such tests. At least one reply was received from every state, with some states returning as high as six filled in questionnaires. It was difficult to determine the exact nature of the work in a few states due to contradictory answers. Some states simplified their replies by returning one questionnaire for all concerned with rapid soil testing. A summary of the information obtained in this survey is presented here.

USE OF TESTS BY STATES

Five states, namely, California, Nevada, Arizona, New Mexico, and Florida, reported no use of the rapid soil tests. The reasons given varied from that of lack of funds to unsatisfactory results with those tried. Seventeen states reported only a limited use of such tests. It is interesting to note that most of these states are located in two sections, namely, the southern Atlantic and Gulf states and the northwestern states east of the Rockies. The reasons given for the limited use of rapid tests were many. The principle ones were lack of funds or personnel to carry out the tests, no means of checking the results against soils of known fertility, very little demand for this kind of work, and the belief that a good observer in the field could guess as well as the one making the determinations. The remaining states reported extensive use of many different kinds of rapid tests. These states lie primarily in the central western area, the corn belt section, and the eastern Atlantic states. Most of these states indicated this kind of work was done rather extensively in order to give better advice and service to the grower and farmer. The use of the rapid soil tests as presented by the returned questionnaires is charted by states in Fig. 1. The states in which no cross hatching appears reported no use of the methods. Limited use is shown by the vertical lines and extensive use by horizontal lines. The meaning of the terms limited and extensive was not definite. Limited seemed to indicate that not many of a single test or only a few of many of the different kinds of tests were made. Extensive was used when a large number of single tests or many different kinds of tests were made on the individual samples.

[1]The material presented here was assembled and prepared by the author upon the request of the late Dr. N. A. Pettinger, Chairman of the Sub-committee on Soil Testing of the general Committee on Fertilizers of the Society and was first reported upon at the annual meeting of the Society in Chicago, Ill., December 6, 1935. The report was submitted for publication upon request of the Sub-committee. Received for publication January 28, 1936.

[2]Associate Professor of Soil Technology, University of Maryland, College Park, Md.

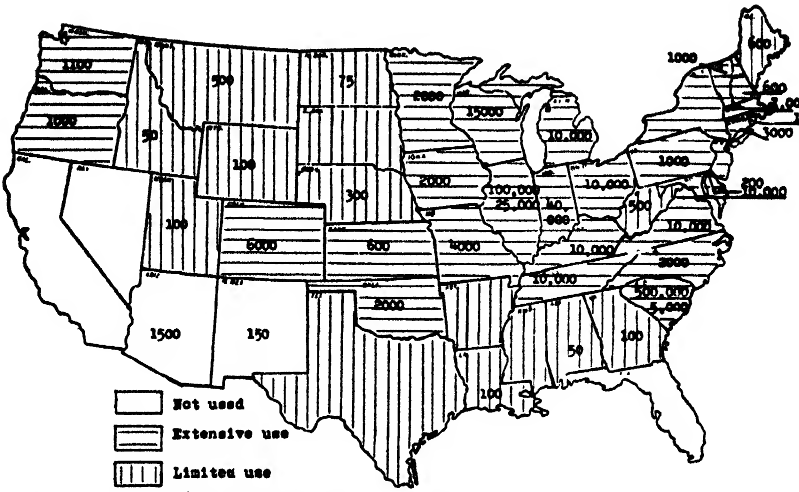

FIG. 1.—Use of rapid soil tests by states and the number of samples tested annually.

Many different kinds of tests and procedures were reported in use. Some states were using several different methods for the same elements. Frequently, the returned questionnaire did not contain complete data as to the methods used. A few states listed the regular long and routine laboratory procedures with a cost as high as $10 per sample as being used to estimate the lime and fertilizer needs of samples received. The methods and details varied so by state and even within some states that it was impossible to tell exactly the methods used by some workers. The summary was made by individual tests, such as pH values, lime requirement, phosphorus, and potassium, instead of by methods. The replies to the other questions were grouped as much as possible under similar headings.

pH VALUES

Soils were tested for their pH value more than for any other determination. This is shown by the horizontal lines in Fig. 2. Forty states were making these determinations. Even states which reported no use of rapid tests stated that they were making many pH tests largely as an indication of alkaline conditions. Arkansas, Florida, Illinois, Iowa, Missouri, Utah, Washington, and Wyoming did not make any pH determinations on the samples submitted by the farmer.

The pH values were determined for the most part by various modifications of the colorimetric methods. No one of these modifications seemed to predominate over the others. In addition, many states used one or more of the various commercial tests for pH determination. The commercial pH tests arranged in order of decreasing use were Truog-Hellige, LaMotte, LaMotte-Morgan, and Soiltex. Ten states reported the use of some form of electric potentiometer. Only one state reported the use of the glass electrode, although it is known that other states are using it.

LIME TESTS

Most of the states which did not make pH determinations used some form of lime requirement. Twenty-five states, as shown by the vertical lines in Fig. 2, reported various kinds of such determinations, the most consistent one being various modifications of the thiocyanate tests. Several used the commercial product known as Rich-or-Poor, while many made their own. Six states reported the Truog lime requirement test still in use. Often there was considerable difference between the methods used by different departments within a state. That is, the extension staff and county agents would be using one or more kinds and the experiment station workers still others. Only one state, Washington, which used the rapid tests, made neither pH nor lime requirement determinations.

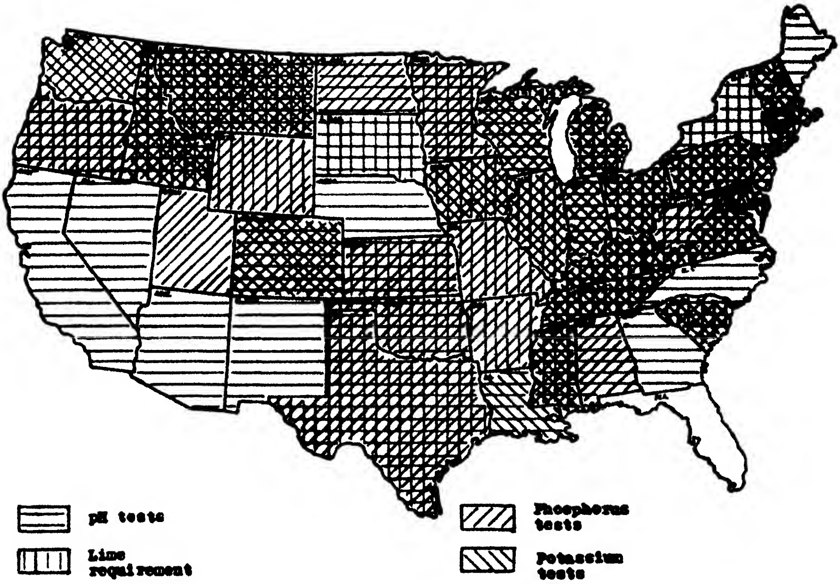

FIG. 2.—Use of rapid soil tests for pH value, lime requirement, phosphorus, and potassium by states.

PHOSPHORUS

The results of the reports for phosphorus indicated this element was deficient in most soils. Thirty-six states reported the use of one or more methods for determining such deficiency. The largest interest seemed to be centered in the middle western and eastern states, although all of the northwestern states make these tests. This is illustrated by the diagonal lines sloping to the right in Fig. 2.

For brevity, the weak acetic acid extraction for deficiencies and the various sodium acetate extractions will be called the Spurway and Morgan methods, respectively. Sixteen states located mostly east of Ohio, reported the use of various modifications of these methods.

The stronger extracting solutions, such as the Bray, Truog, and their respective commercial products, were used in 21 states. These methods were used for the most part in the states lying west of Ohio, although several of the states using the weaker extracting solutions used one or more of these tests for some soils. While 13 states indicated the use of the Bray procedure, only 7 of these used it alone. Thirteen states indicated the use of the Truog method with only five depending solely on this method. The various modifications of Morgan's method were used in 14 states with only 8 using it exclusive of any other phosphorus test. The Spurway phosphorus tests were made in five states but only two states relied entirely on it. The Purdue or Thornton phosphorus method was used in two states. Four states, namely, Colorado, Montana, Oklahoma, and Texas, reported special phosphorus tests of their own. These varied from the various biological tests to special modifications of some of the other tests. Twelve of the 36 states used two or more methods for determining phosphorus needs.

The results of these reports indicate that no one method seems to be entirely satisfactory for all cases. The various modifications of the sodium acetate extractions seemed to be in use more than any other phosphorus tests. This was largely confined to the eastern part of the United States.

POTASSIUM

If the results of the questionnaire can be used as a criteria, the need for potassium is not as great as phosphorus or lime. Only 24 states reported making this test. Of this number, several states made them only on request. The central corn belt, northeastern, and central Atlantic states carried on the most of these potassium estimations. Eleven states reported the use of Morgan's method and 8 of this number depended entirely on it. The Spurway procedure was made in seven states with only three depending entirely on this test. Potassium needs were detected in eight states by Truog, Bray, LaMotte, and Thornton methods. Each method was used by two different states.

OTHER TESTS

Determinations for soluble calcium and magnesium were reported for 20 states. These states were largely those in which the Morgan or Spurway methods for phosphorus and potassium were used. Such tests were centered largely in the east central and northeastern sections of the United States. A few states indicated that determinations were made for these elements occasionally and only on request. Organic matter determinations were made when requested in 10 states. Although these 10 states seemed to appear at random in the United States, the largest number was in the northeastern section. The methods in use varied from that of combustion to various modifications of the rapid titration methods. Special tests for nitrate nitrogen were used in 10 states exclusive of those doing the Morgan or Spurway tests. These states were not confined to any special section of the country. Alkali tests were made in most of the western

states. Eight states reported specific alkali tests, although many states indicated that they obtained something as to the alkali condition by the use of other tests. These rapid tests are supplemented by plant tests in 14 states. In many of these states the number of plant tests was not large, as the opportunity of obtaining the material for such determinations was limited. Some indicated that it probably would be desirable to make these plant tests, but that it was impossible to do it.

NUMBER OF SAMPLES

Nine states reported no record kept of the number of rapid determinations made. This is shown in Fig. 1 by the states which have no number in them. In order to get a better picture of this situation, the states have been grouped according to the total number of tests reported. Thirteen states reported 500 or less tests during the past year. These states were Alabama, Delaware, Georgia, Idaho, Kansas, Louisiana, Montana, New Mexico, North Dakota, Rhode Island, Texas, Utah, and Wyoming. It will be noted that most of these states are in the western and southern part of the country. Three states; namely, Maine, New Hampshire, and Pennsylvania, reported between 500 and 1,000 tests during the past year. Eight states indicated they made from 1,000 to 2,000 such determinations. These states are Arizona, Iowa, Minnesota, North Carolina, Oklahoma, Oregon, Vermont, and Washington. Only two states report more than 2,000 and less than 5,000 tests for 1934. They are Connecticut and Missouri. Five thousand to 10,000 rapid soil tests were reported for Colorado, Maryland, Massachusetts, Michigan, Ohio, South Carolina, Tennessee, and Virginia. The totals for South Carolina and Virginia are exclusive of the lime or pH tests. There is an indication that if these tests were included the figures would be much higher. Four states reported more than 10,000 tests during the past year, including South Carolina with 500,000 for pH, Illinois with 100,000 for lime requirement and 25,000 for phosphorus, Indiana with 40,000 rapid soil tests, and Wisconsin with 15,000 determinations. In these states which reported the highest number many of the tests were for single items such as pH value and lime requirement. The eastern corn belt states seemed to be the center of the rapid soil testing. if numbers can be used as an index. The central Atlantic states indicate another center. If the tests were based on the number per farm or square mile of tillable land, this latter area would undoubtedly be the greatest center.

COSTS

The estimation of the costs was from a fraction of a cent to $10 a sample. Since the cost was figured in many different ways, it was impossible to make any average. Many reported the cost for chemicals or solutions alone and others included the cost for labor in addition. Different states indicated the use of the same methods, yet the cost varied considerably. Where single tests, such as pH or phosphorus, were made, the cost was nearly always much less than that where a series of elements was estimated. A majority of the estimates fell between 10 and 50 cents per sample.

TESTING SERVICE

The reply to the question pertaining to the personnel or to the position and employment of those making the tests indicated that for the most part they were made by the experiment station and teaching staff. Only two states, Michigan and Vermont, reported the work being done entirely by the extension service. There were 18 states in which the extension staff cooperated in this service. All of the testing was done by the experiment station or teaching staff in 20 states. This same group of workers assisted in making the tests in 20 other states. The county agents made most of the tests in North Dakota. They were also important members of the testing staff in 15 other states. Agricultural teachers in the various vocational schools did some soil testing in 18 states. Only six states reported much of any testing by commercial companies. It is doubtful if this is the true picture of the situation since a large number of workers in another portion of the questionnaire indicated they served as advisors for commercial representatives in rapid soil testing. It would seem that for the most part the responsibility of soil testing falls upon the experiment station and teaching staff.

In this connection it is interesting to note that, although the extension service was solely responsible for this service in two states, they financed it entirely in six states. Thirty-nine states indicated that it was under the supervision of the experiment station and teaching staff, with the extension service cooperating in paying the bill in nine of these states. In 25 states the cost was borne entirely by the experiment station and college departments. The departments concerned with rapid soil testing were agronomy, bacteriology, chemistry, botany, and soils. The replies indicate that very few of these states wish to pass this cost on to the farmer or layman, as 40 states made no charge for this service. In four states, namely, Colorado, Maryland, Montana, and Tennessee, a charge was made under certain conditions. This varied from 25 to 50 cents per test. It seems as if a charge was made only to commercial companies and large farm organizations.

The trend of the replies to the question pertaining to method of handling this service in the different states indicates a growing tendency toward centralization or absolute control of rapid soil testing by having it done at one place under the supervision of specially trained men. Five states indicated that under the present conditions this service could be handled better by field men or agents rather than to have all tests made in one central place. Under these conditions the experiment Station or extension staff regulated the service by supplying the testing reagents or designated the ones to be used. Twenty-three reported some training being required for the testers. The requirement indicated by most of these 23 was nothing other than a college degree. Fifteen states indicated that they encouraged the county agents, agricultural teachers, and commercial men in making the tests. Eight states reported a similar encouragement but only to a very limited extent. In 23 states there was no encouragement at all. Most of these states indicated that they did not believe in such encouragement.

It is interesting to note that 30 states reported either no testing by fertilizer or similar commercial companies in the state, or if it was done, it was without the sanction of the experiment station. Seventeen states reported that they were unofficially acting as advisors or helping the various commercial men who are making the tests. There were a few states which reported that testing by commercial men was encouraged. Many expressed the belief that it should be encouraged if the tester was conscientious. Some reported that much of the testing by commercial representatives was biased or not properly done and for that reason none of it should have the sanction of the experiment stations.

INTERPRETATION OF RESULTS

It seems as if the majority of the states recorded the results of their rapid tests by symbols or letters. These were sometimes changed to pounds per acre before being sent out to the farmer with recommendations. Even though many of the states were very strongly in favor of and placed considerable value on these rapid tests, they desired from the one submitting the sample much more information before interpreting the results. Many indicated such data as valuable, if not more so, than the results of the rapid tests. The things considered in addition to the results of the tests were grouped under four headings, *viz.*, soil information, crop record, economic conditions, and the personal element. Under soil information the following items were listed as being used as supplements to the tests in making recommendations to the farmer: Soil type, origin, chemical analysis, exchange capacity, fertilizer response, plat tests, demonstrational farms' results, pot tests, organic matter, drainage, topography, fertilizer, and lime treatment The following desired facts to support the tests were classed under crop record: Kinds of crops, crop yields, crop rotation, livestock produced, climatic conditions, plant behavior, and visible symptoms of plants. The following suggestions were included under the heading of economic conditions: Type of farming, market, source of farm income, operated by owner or tenant. Under personal element the following things were indicated as being very valuable factors to consider: Type of man, common judgment, experience of agronomist, guessing, and prejudice. This information was obtained in nearly every way possible. Most states reported that it was secured by letter or questionnaire, although sometimes by visits either to the farm or the farmer to the laboratory. Often it was very difficult to obtain any reliable information from the layman.

SOIL SAMPLES

The question pertaining to the treatment which the soils undergo in the laboratory was not very well answered. Most of the states which replied indicated that the samples were either air-dried or partially air-dried. Some stated that the samples were screened, although several stated they were only mixed. The 20-mesh screen seemed to be the most popular, although everything from 10- to 60-mesh was suggested as being in use. About half the states indicated that the samples were run as soon as received. In most of the other

states they were allowed to accumulate until a large number were on hand, then the determinations made. Thirty-one out of the 36 states replying to the question pertaining to the sampling and testing of subsoils indicated that such samples were secured only occasionally. Some desired subsoil samples along with the other samples largely to aid in identify the soil. Some states indicated they had carried on extensive studies in comparing the rapid tests with field response to fertilizer and lime treatments. Most states indicated that this had been done only to a limited extent. The information received regarding the preparation of the samples and standardization of the test suggest the need of more uniformity and coordination if the work in the different states can be compared.

FUTURE OF SOIL TESTING

The demands for this service and the opinions on values of the tests in use were answered by practically every state. Forty-two states indicated that such demands were increasing and six of these stated that the increase was very rapid. Even in the states not making such determinations at the present the demands for this service were increasing. Four states, Kansas, Minnesota, New York, and Utah, reported that there was neither an increase or decrease and one state, Alabama had a decrease in demand for this service. Since 22 states expressed the belief that the tests in use at the present were unsatisfactory or inadequate, there is an indication that there is much need for improvement. Twelve states reported that the present tests were fairly satisfactory and 6 that they were practically satisfactory. These last 18 states are largely those in which the largest number and more complete tests were made. For the most part the unsatisfactory experience with the rapid tests were from the states which reported only a limited use of these methods.

SUMMARY

The reports to the questionnaire prepared by the Sub-committee on Rapid Soil Testing and sent to all states indicated the following conclusions.

The use of rapid tests for determining soil deficiencies is extensive. The middle western, east central, central Atlantic, and northeastern states seem to be the most active in this work.

The tests for pH value was used more than any other single determination.

Lime requirement determinations were made in many states even though pH determinations were made.

The estimation for phosphorus deficiency was made in two-thirds of the states. Many of these states used more than one method which indicated that at the present time no one method is entirely satisfactory.

The rapid determination for potassium was much more limited. The corn belt states, east central, central Atlantic, and northeastern states were the centers for these tests.

Very few states made separate tests for calcium and magnesium unless it was included in the method used in making other determinations.

Organic matter, nitrate nitrogen, alkali, and plant tests were reported as being made occasionally by some states. The eastern-corn belt states made the largest number of rapid soil tests, with the central Atlantic states a close second.

It is very difficult to determine the cost since the methods of reporting varied considerably.

The responsibility of the rapid soil testing fell for the most part on the experiment station and teaching staffs. County agents and agricultural teachers made a large portion of the tests in some states, although many states indicated that this was not very desirable.

For the most part this service was financed by the experiment station or college, although in some cases the extension service bore all of the expense, while in others it was cooperative.

Practically every department which does any soils work reported some work with rapid tests. Due to the unsatisfactory results of the tests often reported by the different workers, the majority believe that centralization of the testing in one or two places in each state would be better. Commercial companies on the whole are not encouraged to offer this service to the farmer.

Most states reported the results of their tests in letters or symbols. It seemed to be more desirable to send the interpretations and recommendations based upon all obtainable information rather than the results of the tests alone.

The results indicated that there needs to be considerable collaboration on the treatment of the soil samples and interpretations of the tests made before a comparison of methods can be made. At the present time the most of the states indicated that the rapid tests have been checked under field conditions only to a limited extent. The demand for the use of these tests is increasing rapidly. Since these tests are based on fundamental research and are limited in themselves, very few workers felt that a state of perfection in rapid soil testing had been reached.

AGRONOMIC AFFAIRS

STUDENT SECTION ESSAY CONTEST

THE American Society of Agronomy has agreed to sponsor the student essay contest inaugurated several years ago by the Committee on Student Sections. For the best papers submitted three prizes will be awarded as follows:

1. $15.00 and 1 year's subscription to the JOURNAL.
2. $10.00 and 1 year's subscription to the JOURNAL.
3. One year's subscription to the JOURNAL.

Essays must be prepared by undergraduate students. Papers should be typed, double-spaced, and not over 3,500 words in length. Abstracts should be included as it is hoped that the winning papers may be published in abstract form in the JOURNAL.

Any one of the following topics may be used:

1. Pasture Improvement in the United States.
2. Controlling Noxious Weeds.
3. Breeding for Disease Resistance as a Basis for Improving Farm Crops.
4. The Importance of Soil Conservation.
5. Soil Water in Plant Growth.
6. The Rôle of Some Nutrient in Crop Production.

Papers must be in the hands of the Chairman of the Committee on Student Sections, Dr. H. K. Wilson, University Farm, St. Paul, Minnesota, not later than November 1, 1936.

PROGRAM FOR MEETING OF THE NORTHEASTERN SECTION OF THE SOCIETY

THE following program has been arranged for the meeting of the Northeastern Section of the Society which is to be held at the West Virginia Agricultural Experiment Station, Morgantown, West Virginia, June 24 and 25.

WEDNESDAY, JUNE 24

8:30 A. M.	Assemble at Oglebay Hall (Room 204)
9:00 A. M.	Agronomy Farm:
	Corn breeding
	Sweet clover breeding
	Small grain nursery
10:30 A. M.	Animal Husbandry Farm:
	Response of pasture to fertilizers and lime
	Response of alfalfa to fertilizers and lime
12:30 P. M.	Lunch at University Cafeteria
2:00 P. M.	Reedsville Homestead Project:
	Response of potatoes and corn to fertilizers
	Cooperative potato fertilizer experiment
6:15 P. M.	Banquet and Business Meeting (place to be announced):
	Welcome, President C. S. Boucher
	(Introduced by Dean F. D. Fromme)

Response, J. A. Bizzell, President, Northeastern Section
Business Meeting
Announcements

THURSDAY, JUNE 25

8:00 A. M. Start for Lakin, W. Va., via Ohio River road
11:30 A. M. Lunch at Parkersburg
1:30 P. M. Arrive at Lakin, W. Va.:
Inspect field plats
Response of various crops to fertilizers and green manures
Response of tobacco and legumes to various pH levels
Crop rotations
Lespedeza plats
Tobacco breeding
Watermelon breeding
(Field experiments with vegetables are also located at Lakin)
5:00 P. M. Adjournment

It is expected that arrangements will be made at one of the University dormitories to accommodate visitors Tuesday and Wednesday nights, June 23 and 24. If preferred, excellent hotel accommodation may be obtained in Morgantown at reasonable rates. For those who desire to visit the pasture experiments located on the Wardensville Farm in the eastern part of the state, arrangements will be made to do so on June 26 Here is located a bluegrass pasture involving approximately 40 acres on which the response to fertilizers is being measured by grazing animals as well as by clipping the grass under both permanent and movable cages.

A DIGEST OF PASTURE RESEARCH LITERATURE

DR. A. J. Pieters, Principal Agronomist of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has compiled a digest of pasture research literature in the continental United States and Canada for the period of 1885 to 1935, and the Department is offering the digest in mimeographed form free of charge to all of those interested as long as a rather limited supply lasts.

In a foreword to the digest, P. V. Cardon states, "This digest is offered as a guide to research workers who are formulating research projects with pasture crops and with methods of establishing, maintaining, and utilizing pastures." While Dr. Pieters is credited with the final compilation of the digest and with all the notes and comments that accompany the 704 separate citations, others who have contributed to the enterprise include C. R. Enlow, who initiated the digest in 1933, and H. N. Vinall, M. Hein, and E. M. Coffman.

The digest is limited to pasture literature, hence no range literature is included. It relates chiefly to those parts of the United States and Canada which lie between the Atlantic Seaboard and the 97th meridian of longitude, although publications relating to the humid Pacific Coast region and to irrigated pastures in the West are also included. The material is arranged first by states followed by sections

dealing with publications of the U. S. Dept. of Agriculture, Canadian contributions, and a miscellaneous section. A comprehensive index adds materially to the value of the digest for reference purposes.

NEWS ITEMS

F. S. WILKINS, Research Assistant Professor of Agronomy at Iowa State College, died on March 31 at the age of 46. Since his appointment to the staff at Iowa State College in 1914, he had been in charge of forage crops investigations, and the results of his research have been published in a number of experiment station bulletins and journal articles.

DR. W. H. MACINTYRE, head of the Department of Chemistry, University of Tennessee and consulting chemist for the TVA, has been selected to receive the 1936 Charles Herty award for outstanding service in the field of chemistry in the South.

S. D. CONNER, Research Chemist in the Department of Agronomy, Indiana Agricultural Experiment Station, Lafayette, Ind., died last month following an appendicitis operation. Professor Conner had long been active in affairs of the Society and held three important committee assignments at the time of his death.

JOHN W. GILMORE, Professor of Agronomy, University of California, resident at Davis, is at present in Chile, having sailed with Mrs. Gilmore on February 7, to return some time in August. On the invitation of the Chilean Government, Professor Gilmore is instructing the young men who will teach and advise the prospective settlers on virgin lands in the Central Zone of Chile. The soil and climatic conditions of this region correspond closely to those found in California, between Colusa and Merced. This is the second time the Republic of Chile has called upon Professor Gilmore to help in the solution of her problems. Besides serving at Cornell, Pennsylvania State College, and California, he has, at various times also been instrumental in organizing agriculture and agricultural education in China, the Philippines, India, Hawaii, the Dominican Republic, and Mexico.

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APPARATUS FOR THE MEASUREMENT OF CO_2 EVOLVED DURING THE DECOMPOSITION OF ORGANIC MATTER IN SOILS[1]

B. N. Singh and P. B. Mathur[2]

DETERMINATIONS of CO_2 produced during organic matter transformations in soils are generally made by absorption of CO_2 in baryta solution which is subsequently titrated against standard HCl. In the course of investigations on microbial activity as evidenced by evolution of CO_2 following additions of organic matter residues to the soil, the method of gas analysis was found to be convenient and an apparatus for this purpose has been constructed in this laboratory. Samples of moist soil were placed in 500-cc soil chambers and the CO_2 production determined by analyses of the gaseous mixtures by means of a Haldane absorption bulb.[3] The amount of CO_2 evolved per 100 grams of dry soil may be easily calculated if the percentage content of CO_2 in the gaseous mixture and the total amount of gas in the soil chamber are known. Analysis by means of a KOH bulb gives the percentage CO_2 content and the total volume of gas in the chamber is calculated in the following manner: The decrease in the pressure of the gas in the soil chamber following the withdrawal of a sample for analysis is noted and the volume of this test portion at the atmospheric pressure measured. From these data the desired total volume of gas x is easily computed by the formula $x = \frac{V.H}{h}$, where V = volume of the test portion withdrawn at the atmospheric pressure, H = atmospheric pressure in mm paraffin,[4] and h = decrease in pressure in mm paraffin in the soil chamber.

The KOH bulb (C) and the compensation pipette (B′) of the apparatus (Fig. 1) are of the type employed by Haldane. The 5-cc measuring pipette (B) is graduated into hundredths of a cc, the mer-

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication January 25, 1936.

[2]Kapurthala Professor of Plant Physiology and Agricultural Botany and Assistant, respectively.

[3]Haldane, J. S. Methods of Air Analysis. London. 1912.

[4]In determination of H, weight of 10 cc paraffin (in specific gravity bottle previously calibrated with mercury) = 7.88 gram; therefore, its density = 0.788 and H = 760 × 13.6/0.788 = 13,110 mm.

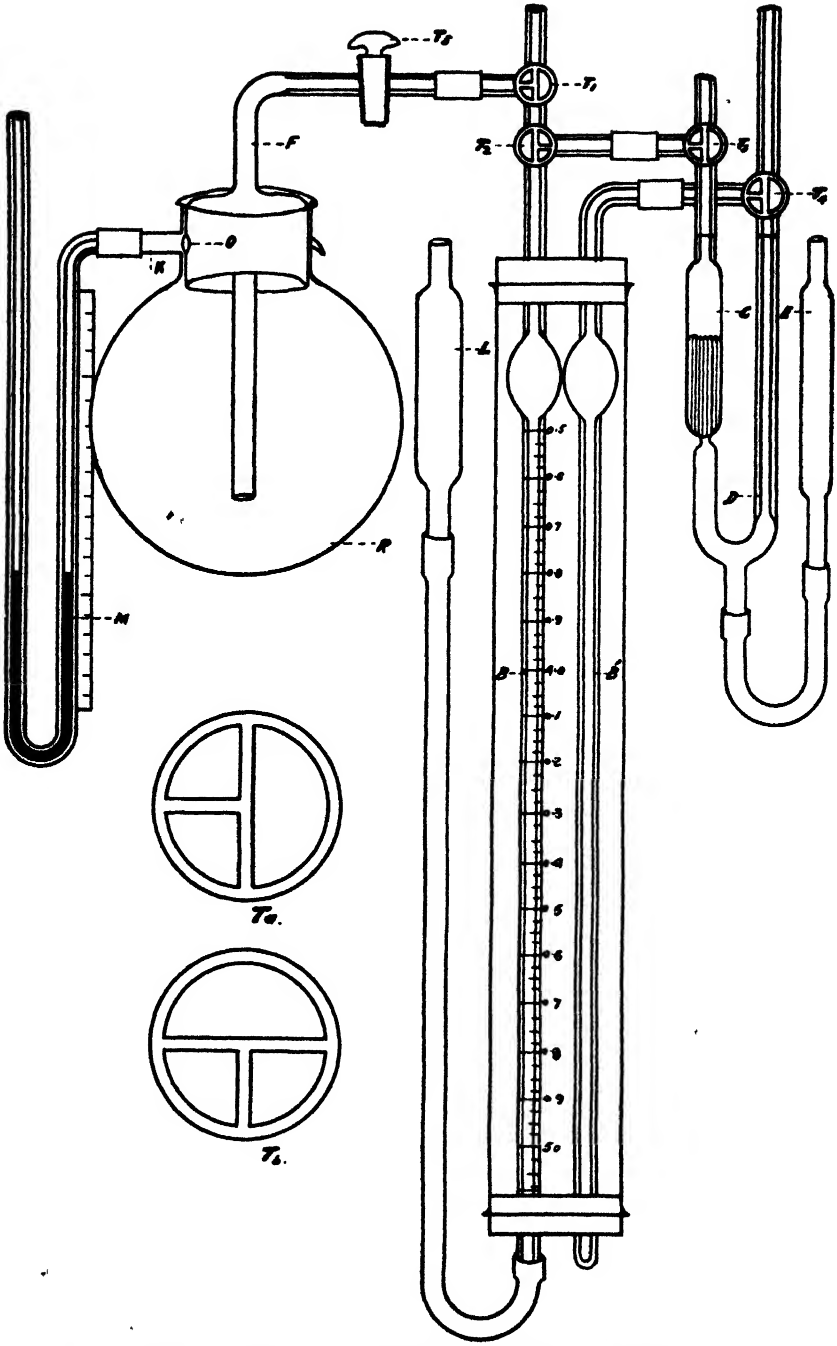

FIG. 1.—Apparatus for the determination of CO_2 production in soils

cury level adjustments being made by means of the bulb (L). The measuring pipette (B) and the compensation pipette (B′) are enclosed within a glass jacket the water in which is kept stirred in order to maintain a uniform temperature. The soil chamber (R) possesses a ground glass stopper to which is attached the tube (F), one extremity of which projects into the chamber while the other carries a tap (T_5). To the soil chamber is also attached a side-tube (K) with which is connected a manometer (M). By turning the ground glass stopper the soil chamber can be put in communication with the manometer through the orifice (O).

Samples of moist soil equivalent to 50 grams of dry soil which had been passed through a 2-mm sieve and thoroughly mixed were placed in the soil chambers. In all cases the moisture content in the soil was adjusted to 20 to 25% by the addition of distilled water. Dry CO_2-free air was allowed to enter the soil chambers which were then placed in a thermostat and incubated at 30 ± 0.1° C for several hours. After fixed intervals the soil chambers were removed from the thermostat and connected with the absorption apparatus and the manometer (M) as shown in Fig. 1. The manipulation is easy. Turning the tap T_2 in the position Ta, the KOH levels in the bulb (C) and the side-limb (D) are set by opening the taps (T_3 and T_4) and sliding the bulb (E) up or down, the taps (T_3 and T_4) being subsequently closed to the atmosphere. By means of the levelling bulb (L) the mercury in the pipette (B) is brought to the tap and the tap T_1 is turned in the position Tb. Now the tap T_5 is opened and the soil chamber rotated on its ground glass stopper so that it communicates with the manometer (M). The pressure indicated by the manometer is read and a portion of gas withdrawn into the pipette (B) by lowering the levelling bulb. The decrease in pressure in the chamber following the withdrawal of the gaseous sample is noted. Subsequent to this the tap T_5 is closed, the tap T_2 turned as shown in Fig. 1, and the volume of the gas withdrawn determined after setting the potash levels in C and D.

Knowing the decrease in pressure in the soil chamber and the volume occupied by the sample withdrawn at atmospheric pressure, the total amount of gas in the chamber is easily computed. The procedure for analysis of the mixture in order to determine the CO_2 content is as follows: The sample just withdrawn is freed from CO_2 so that all the capillaries of the apparatus may be filled with nitrogen and oxygen. Sampling is done by the washing method[5]. The gas samples are drawn in and sent out of the measuring pipette by means of the mercury levelling bulb, one or two washings usually being given. After the final washing is completed about 5 cc of the sample are taken into the pipette (B), the potash levels being set as before. The subsequent process consists in sending the gaseous sample back and forth several times into the KOH bulb. When the CO_2 has been completely absorbed the decrease in volume of the test sample is noted, after setting the potash levels in the usual fashion.

[5]CARPENTER, T. M. A comparison of methods for determining the respiratory exchange of man. Carnegie Inst. Pub. 1915.

The length of the intervals after which analyses are carried out is determined by the rate of CO_2 production from the soil. The organic matter decomposition in the soil being of the nature of oxidation, oxygen is absorbed and increasing amounts of CO_2 accumulate in the soil chamber. To know the limit beyond which concentrations of CO_2 will result in depressing the rate of evolution of CO_2, five series of experiments were performed. In each series the sub-samples for individual experiments were drawn from a single sample of soil. Each of the five samples of soil was passed through a 2-mm sieve and the moisture content adjusted to 20% in all of them. Various concentrations of CO_2, ranging from 0 to 11%, were allowed in the soil chambers and the total CO_2 production was determined after 12-hour periods. In each series 12 experiments were performed, each experiment being run in triplicate. The average amounts of CO_2 produced in the various experiments are shown separately in Fig. 2.

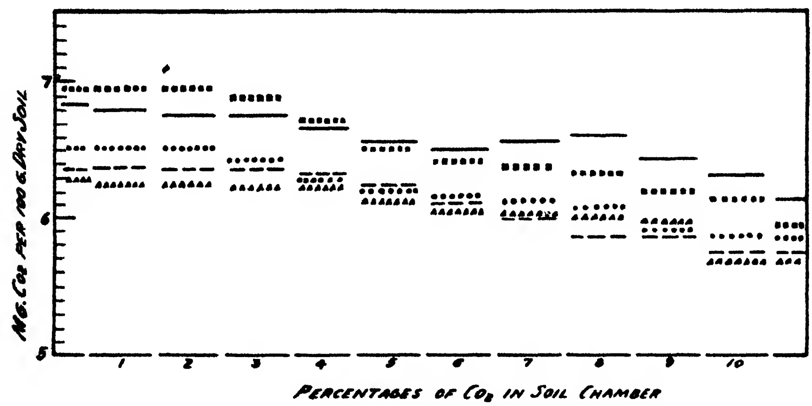

FIG. 2.—Average amounts of CO_2 evolved under various concentrations of CO_2.

The data indicate that a rise in the concentration of CO_2 beyond 4% will result in a distinct depression in the rate of CO_2 production from the soil. Evidently the interval after which the CO_2 concentration will rise above 4% will depend upon the rate of CO_2 production from the soil as also upon the soil/gas-space ratio in the soil chamber. With samples having a high rate of CO_2 production smaller amounts of soil should therefore be used.

CAPILLARY CONDUCTIVITY MEASUREMENTS IN PEAT SOILS[1]

L. A. Richards and B. D. Wilson[2]

During the summer of 1934 an apparatus was constructed for the purpose of measuring the capillary conduction of water in peat soils. The study was intended to include peats that had never been cultivated and those that had been tilled for different periods of time. Although it became necessary to discontinue the investigation before it was completed, the technic that was employed in the work and the results which were obtained appear to be of sufficient interest to justify the present report.

The readiness with which water is conducted in soil may be expressed in terms of a conductivity factor defined as the ratio of flow to water-moving force. In this paper flow is expressed as the number of cc of water which in 1 second cross an area of 1 square cm in the soil perpendicular to the flow. Water-moving force is expressed in dynes per gram. In a horizontal direction the water-moving force is equal to the pressure gradient in the soil water divided by the density of the water.

APPARATUS EMPLOYED AND EXPERIMENTAL PROCEDURE

The experimental procedure was similar to that described in a previous paper by one of the authors,[3] but improvements were made in the design and arrangement of the apparatus. Fig. 1 shows one of the capillary-conductivity units used in the present experiment. The column of soil to be studied was mounted in the telescoping brass cylinders A and A′ between two hollow porous cells B and B′ which were made especially for the purpose. The flow of water to and from the soil column took place through the large tubes C and C′. The water in the cells, and hence in the soil, was automatically maintained at a pressure less than atmospheric pressure. It is desirable to use atmospheric pressure as the zero pressure reference; thus the water may be said to have been under tension. Using the term tension or capillary tension for the negative pressure existing in water in an unsaturated soil avoids the necessity of dealing with a negative quantity. The difference in the tension in the soil water at the two ends of the soil column was measured by a differential manometer D which was connected through tubes E and E′ to small-bore porous tubes extending across the ends of the soil column. Manometer F connected to one of these tubes measured the tension in the soil water at one end of the column. The frame G, connected to a stranded cable passing over a pulley shown at the left of the figure, was used to subject the column of soil to a constant compression of 708,000 dynes per square cm. The initial length

[1]Contribution from the Departments of Physics and Agronomy, Cornell University, Ithaca, N. Y. Received for publication February 27, 1936.

[2]Formerly Instructor in Physics, Cornell University, now Research Assistant Professor of Soils, Iowa Agricultural Experiment Station; and Professor of Soil Technology, Cornell University, respectively. The authors wish to express their appreciation to Dr. R. C. Gibbs for making available the constant temperature room of the Department of Physics where this work was done.

[3]Richards, L. A. Capillary conduction of liquids in porous mediums. Physics, 1:318. 1931.

of each soil column was 12.1 cm and in each case the decrease in length during the 4½ months of the experiment was less than 0.2 cm. The inside diameter of the brass tube containing the soil was 12.1 cm.

Fig. 2 shows the two capillary conductivity units, completely assembled, which were used in the investigation. Cloth wicks served to keep the air in the water-tight wooden chambers saturated with moisture in order to prevent the evaporation of water from the soil column. The flow of water to and from each soil column was read by means of burette tubes. A felt-padded wooden hammer, H, operating about 20 times a minute, served to agitate the mercury in the vacuum

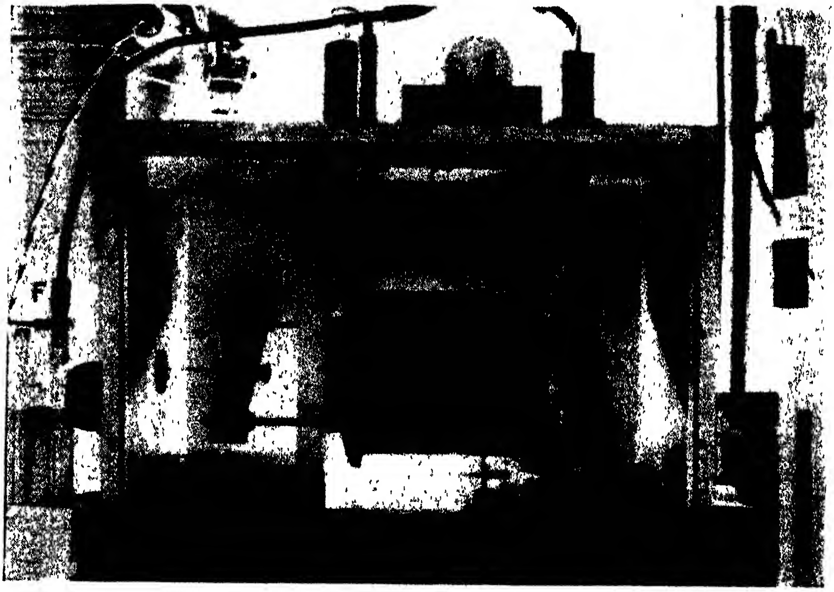

FIG. 1.—Apparatus used for measuring the capillary conductivity of water through soil.

pressure control manometers, I. These manometers, the principle of operation of which has been described elsewhere,[4] automatically maintained the water tension at various parts of the system within 0.5 mm of mercury of the desired values. A steady flow of water was assumed to obtain when the flow to and from the soil column differed by less than 1%. During the experiments the temperature of the room was held at 25° ± .05° C.

In calculating the capillary conductivity of the soil the following formula was used: $K = Q/t \times Ld/A \, \Delta p$, where K is the capillary conductivity, Q/t is the cc of water per second passing through the soil column, L is the length of the soil column in cm, A is the area of the soil column in square cm, d is the density of water in grams per cc, and Δp is the difference in pressure (difference in tension) of the water at the two ends of the column expressed in dynes per square cm.

[4]RICHARDS, L. A. Low vacuum pressure control apparatus. Rev. Sci. Instruments, 2:49. 1931.

SOILS USED

Two peat soils were used in the experiments. One of the soils was collected from the surface zone of a virgin deposit of granular, well-decomposed woody peat. The other soil was taken from the plowed layer of an adjacent area that

FIG. 2.—Two capillary conductivity units showing the arrangements used for controlling and measuring the flow of water through the soil column.

had been cultivated annually for a period of about 50 years. The structure of the soil had been greatly modified owing to cultural operations and the sample was composed largely of finely divided material. The samples of soil were collected in June, 1934, and placed immediately in air-tight containers to prevent loss of moisture.

On September 1 each of the soils was transferred to one of the telescoping cylinder units of the apparatus. In filling the cylinder with the virgin peat, an attempt was made not to destroy the structure of the material. The finer particles were worked in and around the larger lumps so that large voids would not exist in the soil column.

RESULTS OF THE EXPERIMENT

The data of Table 1 show the capillary conductivity of the soils during the course of the experiment at different capillary tension values. Capillary tension is expressed as the number of cm of water column necessary to produce the tension. The results of the work, which should be regarded as preliminary only, reveal an important property of peat soils. It may be seen in the table that an equilibrium flow was first attained with the virgin soil.

TABLE 1.—*The capillary conductivity of water in peat soils at different capillary tension values.*

Date of record	Capillary tension, equivalent water column in cm	Capillary conductivity, seconds $\times 10^{11}$
	Virgin Peat	
Oct. 1	22.8	614.0
Nov. 8........	193.7	0.0
Dec. 20.......	9.5	2,243.0
	Cultivated Peat	
Oct. 23........	21.9	2,810.0
Dec. 20.......	73.3	20.7*
Feb. 8........	71.4	12.8*

*Since steady flow was not attained, the average of the inflow and outflow was used in calculating these conductivity values.

After making the conductivity calculation recorded for October 1, the capillary tension was set at 193.7 cm of water. This setting revealed the rather surprising fact that even at the relatively high moisture content of the soil[5], the water seemed not to be present in a continuous liquid phase because flow through the column ceased. The tension was then reduced to 9.5 cm of water, and as was expected, the conductivity increased to a relatively high value.

The relation of tension to conductivity cut-off in the case of the soil that had been cultivated was similar to that of the virgin soil. It may be seen in the table that increasing the tension from 21.9 to 73.3 cm of water reduced the conductivity to less than 1% of its previous value. The value of K calculated on December 20 was not an equilibrium value because the inflow of water to the column exceeded the outflow by more than 1%. Nine weeks later, on February 8, an equilibrium flow had not been attained. During that time the excess of inflow over outflow caused an accumulation of water in

[5]Determinations of the moisture content of the soils at different capillary tensions were not made, but the moisture content corresponding to a water column of 193.7 cm would probably be of the order of 80 to 100% on the basis of dry soil.

the soil column, yet the conductivity continued to decrease. Because equilibrium was approached from the wet side the findings seem to indicate that mobile water from the capillary stream was converted to an immobile or bound phase. Further investigation is necessary in order to explain the observed phenomenon in terms of fundamental processes. An explanation may be found in the replacement of adsorbed or occluded air in the organic colloid-water system by water.

The capillary tension at which the conductivity becomes zero is of practical significance in that it makes known the maximum height to which water can rise by capillary action in a moist soil. Because of the discontinuance of the investigation the capillary tension for conductivity cut-off was not accurately determined for either of the soils. It seems certain, however, that the cutoff would occur at much lower tension values than those which have been found for mineral soils ranging from coarse sand to fine clay.[6]

Zero conductivity occurring at low tensions seems to explain why certain crops growing on peat soils containing relatively high percentages of moisture suffer from drought. When the conductivity is zero and the moisture adjacent to the roots of plants has been exhausted, the plants will suffer drought unless the roots grow out to a new moisture supply

SUMMARY

An apparatus of improved design was used in measuring the capillary conductivity of water in peat soils. A description of the apparatus is given.

At low tensions the soils were found to possess capillary conductivities greater than those that have been reported for mineral soils. However, the capillary conductivity was found to become zero at lower tensions in the two peat soils studied than has been reported for mineral soils.

Difficulty was experienced in measuring the capillary conductivity of peat soils because of the length of time required for the moisture content of the soils to reach an equilibrium value at a given capillary tension.

[6]See footnote 3.

TOXICITY FROM ARSENIC COMPOUNDS TO RICE ON FLOODED SOILS[1]

J. FIELDING REED AND M. B. STURGIS[2]

DURING recent years, farmers in the rice area in southwest Louisiana have experienced considerable difficulty in the growing of rice when it follows cotton which has been dusted with calcium arsenate for boll weevil control. This difficulty is largely confined to the rice area where the soil is flooded for about 3 months during the growing season of rice. The investigations presented here concern observations on arsenic toxicity in certain soils of this rice area.

Arsenic toxicity in soils is no new problem. Large amounts of arsenic are used annually in the spraying of fruit and, in the South particularly, in the dusting of cotton. The greater part of this arsenic finds its way to the soil and the question has been raised as to what toxic effect these accumulations may have on succeeding crops. Headden (6, 7, 8)[3], working at the Colorado Agricultural Experiment Station on the arsenical poisoning of fruit trees over a period of 20 years, found that in the order of time, the use of arsenic as a spray was accountable for the death of a large number of trees. A considerable amount of work on arsenic poisoning has been carried out at the South Carolina Experiment Station (2). It was found that applications of calcium arsenate in cotton boll weevil control had affected the productivity of certain soil types. The coarse-textured gray soils were seriously affected by relatively light applications of calcium arsenate, whereas the fine-textured, dark-colored soils were not seriously affected by applications which would be commonly used in combating the cotton boll weevil.

Further investigations in South Carolina (1) showed that the total amount of arsenic present in a field soil was not necessarily related to the toxicity toward crops. The concentration of soluble arsenic in soils, as measured by collodion bag dialysates, was usually a more reliable index of arsenic toxicity than was the total arsenic present in the soil. Greaves (5) at Utah made a number of determinations of arsenic in various forms, though with no yield correlations, and concluded that the toxicity of arsenic to plants and soil microorganisms is governed by the water soluble soil arsenic.

Still further work the following year at South Carolina (3) indicated that there was a definite relationship between the amount of reactive iron present in the soil and the arsenic toxicity. The gray, light soils, low in reactive iron, were very sensitive to additions of calcium arsenate, whereas the dark, heavy soils, relatively high in reactive iron, were not seriously affected by large amounts of calcium arsenate. In fact, it was shown that additions of ferrous sulfate to soils in

[1]Contribution from the Department of Agronomy, Louisiana Agricultural Experiment Station, Baton Rouge, La. Published with the approval of the Director of the Louisiana Agricultural Experiment Station. Received for publication March 23, 1936.

[2]Assistant in Agronomy and Research Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 436.

which arsenic toxicity had developed benefitted subsequent crop growth, this benefit being due probably to absorption of arsenates by iron hydroxide.

No particular difficulty has been experienced in Louisiana when cotton is treated with calcium arsenate and followed by another crop of cotton or by some other upland crop. Either the applications have not been heavy enough to cause toxicity or the soils have such chemical and physical properties that the arsenic does not exert any effect. On the other hand, as mentioned above, a number of farmers have reported trouble with rice when it follows cotton which has been dusted with calcium arsenate. The rice either gave very low yields or blighted completely. The yield and quality of the straw were not harmfully affected, but the rice heads were empty and unfit for milling.

EXPERIMENTAL

For this study of arsenic toxicity, samples of soils from three different places in the rice area in southwest Louisiana were secured, *viz.*, a Crowley silty clay loam from the Rice Experiment Station at Crowley, Louisiana, and two soils from farms reporting trouble, a Crowley very fine sandy loam, and a Lake Charles clay. Three-gallon pots were filled with these soils and varying amounts of arsenic added to the soils. These pots were planted to rice and determinations made of the total arsenic, water-soluble arsenic, and 0.05N HCl-soluble arsenic in the soil while the rice was flooded and at the conclusion of the test. The rice was cut when mature, the yields computed, and total arsenic determined in the heads and straw separately. Total arsenic in the soil was determined by the method suggested by Greaves (4), modified to use the Gutzeit test as recommended by the A. O. A. C. (10) instead of the Marsh test. The water-soluble and 0.05N HCl-soluble arsenic were determined by the Gutzeit test in aliquots of extracts of 1:10 ratio of soil to extractant. For the arsenic in the rice heads and straw, the method of the A. O. A. C. for arsenic in plants was followed.

DISCUSSION OF RESULTS

It may be seen from Table 1 that with rice arsenic toxicity apparently is dependent upon soil type just as has been found in the case of cotton. No appreciable effect was noticed on the Crowley silty clay loam with arsenic applications up to 150 pounds per acre, while in the case of the Crowley very fine sandy loam, the rice was very noticeably affected by applications of 50 pounds or more per acre. Such applications have not proved toxic to cotton on these soils. Evidently in the presence of the highly reducing conditions which are prevalent throughout the growing season of rice, the arsenates are reduced to the much more toxic arsenites and possibly even to gaseous arsine. This latter condition is evidenced by the fact that there is a decrease in the arsenic content of the soil through the growing season.

The exact extent of the reducing condition that prevails in the soil when it is planted to rice and kept continuously flooded was measured by determining the oxidation-reduction potential of soil samples in pots during the growing season of rice. The Eh, or oxidation-reduction potential, dropped from Eh 0.67 to Eh 0.19 during the submergence. Other tests conducted previously with the Crowley silty clay loam

TABLE 1.—*Effect of calcium arsenate on yields of rice in certain soils.*

Treatment, lbs. per acre	Soil type	Average yield of of straw, grams	Average yield of of head, grams	Head yield gain or loss %
1, No treatment	Crowley silty clay loam	9.0	4.7	0.0
2, 16 lbs. calcium arsenate	Crowley silty clay loam	9.7	6.8	+45.0
3, 50 lbs. calcium arsenate	Crowley silty clay loam	9.0	4.5	—4.2
4, 150 lbs. calcium arsenate	Crowley silty clay loam	9.0	5.5	+17.0
5, No treatment	Crowley very fine sandy loam	37.0	11.0	0.0
6, 50 lbs. calcium arsenate	Crowley very fine sandy loam	35.6	6.0	—45.0
7, 150 lbs. calcium arsenate	Crowley very fine sandy loam	35.2	4.0	—64.0
8, 300 lbs. calcium arsenate*	Lake Charles clay loam	No yield, rice unharvested		

*No pot test was run on this soil. 300 lbs. of calcium arsenate per acre had been used by the farmer and the rice blighted completely.

soil showed that the reduction of sulfates to sulfides took place at a potential of Eh 0.38 or higher. Since sulfate to sulfide reduction is listed in the standard tables as occurring at a lower oxidation potential than arsenate to arsenite reduction, there is every reason from this standpoint to expect reduction of arsenate at least to arsenite.

Most investigators maintain that water-soluble arsenic is an index of arsenic toxicity in soils. It may be seen from Table 2 that no water-soluble arsenic or a very small trace was found in any case, but a close relationship was observed between the 0.05 N HCl-soluble arsenic and toxicity. The amount of dilute acid-soluble arsenic may better represent the arsenic which can affect the plant than does the amount of water-soluble arsenic. In the case of the Crowley very fine sandy loam where toxicity was particularly noticeable with the 50-pound per acre application, the amount of arsenic soluble in 0.05 N

TABLE 2.—*Total arsenic, water-soluble arsenic, and 0.05 N HCl-soluble arsenic in treated rice soils at the conclusion of the test.*

Treatment No.	Total arsenic in soil, p.p.m.	Water-soluble arsenic, p.p.m.	0.05N HCl-soluble, p.p.m.	Arsenic in heads, p.p.m.	Arsenic in straw, p.p.m.
1	2.0	0.0	0.0	0.4	0.3
2	3.0	0.0	0.5	0.5	0.5
3	4.0	0.0	1.0	1.0	0.5
4	6.0	0.0	1.0	1.7	0.7
5	5.0	0.5	0.5	0.8	0.6
6	10.0	0.5	3.5	2.7	1.2
7	20.0	1.0	6.0	5.0	2.5

HCl was three times as great as the amount of acid soluble arsenic in the Crowley silty clay loam which had received an application of 150 pounds per acre.

Some interesting observations were made in connection with the amounts of arsenic put into the soil and their relation to the amounts found during the test and at the conclusion of the test (Table 3). There was a decided decrease in the amount of total arsenic found at the conclusion of the test as compared with the amount at the beginning, in every case, except in the untreated pots. The arsenic content remained practically constant in the untreated pots, while in the treated pots the content tended to drop to the level of the untreated soil, though in no case did it fully fall to this level. The difference between the sum of the amount of arsenic added and the arsenic present in the untreated soil and the sum of the amount of arsenic determined in the soil and in the rice after the rice was harvested is listed in Table 3 as arsenic "unaccounted for." By reference to the amounts of arsenic found in the stalks and heads of the rice crop, it may be seen that a relatively small amount of the total arsenic is removed through the crop. Under the highly reducing conditions prevalent when rice is being grown in a flooded soil, the answer to the question of what happens to this "unaccounted for" arsenic which had been applied as an arsenate might be found in the reduction of a good portion of the arsenates to arsine. This reduction appears to proceed until a certain level of arsenic content is reached, that level being the amount of arsenic occurring in the untreated soil.

TABLE 3.—*Summation of arsenic determinations of pot tests of rice in treated soils.*

Treatment No.	Arsenic added to soil May 31*	Arsenic in soil Aug. 10	Arsenic in soil after harvest	Arsenic in rice heads	Arsenic in rice straw	Arsenic "unaccounted for"
1	0.00	20.00	20.00	0.002	0.002	0.0
2	36.00	40.00	30.00	0.004	0.004	26.0
3	113.00	100.00	40.00	0.004	0.004	93.0
4	338.00	200.00	60.00	0.008	0.005	298.0
5	0.00	80.00	50.00	0.008	0.021	——
6	113.00	150.00	100.00	0.016	0.042	93.0
7	338.00	350.00	200.00	0.020	0.070	218.0

*All results expressed as total Mg of As_2O_3 in soil or rice.

Many cases of the microbiological reduction of arsenical compounds to arsine have been reported, but, in so far as the authors could determine, no special study has been made of the reduction of arsenates to arsine in soil under submerged conditions. Thom and Raper (9) have studied arsenic decomposing fungi in the soil, and have shown that arsenic accumulation in the soil would not ordinarily be expected to occur, since arsenical substances carried to the soil come in contact with decomposing agents which tend to break them into volatile forms. Even if this loss of arsenic were to proceed as suggested, it would take a number of years to remove enough arsenic through this means to make the soil suitable for rice again. In the

cases studied, toxicity had been experienced on the farms for a number of years in succession with rice, though to a diminishing extent. No trouble was had when another upland crop, such as corn or cotton, was planted in place of rice. This would seem to indicate rather conclusively that it is the reduced arsenic compounds, arsenites, etc., which are particularly toxic to rice under flooded conditions.

SUMMARY

Arsenicals used in the dusting of cotton have had a toxic effect on succeeding crops of irrigated rice in certain soils of the Southwest

The effect on the yield of rice of applications of varying amounts of calcium arsenate on different soil types was studied and it was found that the toxic effect was governed largely by the soil type. Rice on the lighter soils was seriously affected by applications of 50 pounds per acre of calcium arsenate, while on the heavier soils 150 pounds per acre were not injurious. No correlation could be found between water-soluble arsenic and toxicity, though a relationship existed between 0.05N HCl-soluble arsenic and toxicity.

Less total arsenic was found in the soil at the conclusion of the test than was present at the beginning. An analysis of the rice heads and straw showed that the loss could not be accounted for by crop removal. The soil was found to be in a highly reducing condition when flooded under cultivation, and it is suggested that this loss in arsenic content might be accounted for by complete reduction to gaseous arsine. Furthermore, the evidence seems to indicate rather conclusively that it is the reduced arsenic compounds, arsenites, etc., that are particularly toxic to rice under flooded conditions.

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EFFECTIVENESS OF FURFURAL PETROLEUM COMBINATIONS IN ERADICATING CERTAIN NOXIOUS WEEDS[1]

H. L. BUCKARDT[2]

THE national loss caused by weeds has been estimated to amount to $3,000,000,000 annually (1).[3] This loss is 12 times the estimated loss from animal diseases, 1⅔ times the annual loss caused by plant diseases, and 3 times the estimated annual loss from insect pests of plants.

Many methods to reduce loss caused by weeds have been utilized by different workers. Among these methods, chemicals have been used with varying degrees of success.

The purpose of this study was to test several furfural-petroleum combinations to determine (a) the effectiveness of the various materials in killing certain weeds, (b) the most effective rate of application, (c) the influence of climatic conditions and time of day on the effectiveness of application, and (d) the rapidity of kill resulting from the application of different chemicals.

METHODS AND MATERIALS

Two general methods were used in applying the furfural-petroleum combinations, *viz.*, individual plant application and broadcasting.

The individual plant treatment method was used in trials on dandelion (*Taraxacum officinale*), broad-leaved plantain (*Plantago major*), and buckhorn (*Plantago lanceolata*) (2). This method consisted of making an application of the chemical on the crown of the plant by the use of a "cane." The cane was a hollow cylindrical tube, 40 inches long, containing an automatic operating device in one end and a cap to permit pouring in of the chemical on the other end. The operating device was so constructed that each stroke of the cane caused the valve to permit an equal quantity of material to flow on the plant.

The broadcast method was used in trials on quack grass (*Agropyron repens*) and field bindweed (*Convolvulus arvensis*). This method consisted of spraying the chemical uniformly over the area to be treated by means of a nozzle hand sprayer.

Following is a list of the furfural-petroleum combinations used in the tests, including both the laboratory number and a statement as to the composition of each:

1847—Stanolex Fuel Oil No. 1 (viscosity of 32 seconds).

1856—Stanolex Fuel Oil No. 1 98% plus 2% hard stanolite.

1849—Stanolex Fuel Oil No. 1 95% plus 5% furfural.

1850—Stanolex Fuel Oil No. 1 77% plus 10% furfural, plus 13% mutual solvent.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill., resulting from a cooperative research project between the University of Illinois and the Standard Oil Company of Indiana. Received for publication March 5, 1936.

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[3]Figures in parenthesis refer to "Literature Cited," p. 442.

1852—Stanolex Fuel Oil No. 3 (viscosity of 37 seconds).
1853—Stanolex Fuel Oil No. 3 90% plus 10% furfural.
1905—Stanolex Fuel Oil No. 3 85% plus 15% furfural.
1854—Road Oil No. 3 (viscosity of 480 seconds).
1855—Road Oil No. 3 95% plus 5% furfural.
1895—Sodium arsenate and sodium silicate solution 20%.

CLIMATE

During the period of the experiment wide differences occurred in the amount of precipitation and extremes of temperature. Since these factors of the environment influenced the effectiveness of the weed killers, a brief summary of these important ecologic factors is given in Table 1.

TABLE 1.—*Semi-monthly rainfall in inches and maximum, minimum, and mean temperatures in °F for July, August, September, and October, 1932.*

	July 1–15	July 16–31	Aug. 1–15	Aug. 16–31	Sept. 1–15	Sept. 16–30	Oct. 1–15	Oct. 16–31	Total
Rainfall, in.	1.58	0.83	2.45	0.18	1.95	1.68	1.28	2.56	12.51
Max. temp., °F	98.0°	98.0°	89.0°	95.0°	89.0°	82.0°	80.0°	77.0°	——
Min. temp., °F	52.0°	55.0°	59.0°	51.0°	47.0°	43.0°	31.0°	28.0°	——
Mean temp., °F	72.8°	81.4°	74.5°	76.6°	70.7°	62.4°	54.5°	52.7°	——

The highest temperature during this 4-month period was 98° F, which is 7° less than the highest temperature recorded at Urbana since 1894. The mean temperature for this period was slightly higher than normal. The rainfall was below normal for July and August but above normal for September and October.

RESULTS AND DISCUSSION

After treatment, observations were made at weekly intervals to determine the effects of the chemicals applied. Frequently, it was found that only the top growth was killed for plants that appeared to be dead above ground after a period of time sent up new growth and continued living. Hence, for a complete record of the results, it was necessary to make final counts several weeks after treatment.

PLANT APPLICATION METHOD

Lawn weeds.—Data are given in Table 2 showing the results of treatments made by the plant application method for three kinds

TABLE 2.—*Percentage of dandelion, buckhorn, and broad-leaved plantain plants killed after applying 4 cc of various chemicals.*

Kind of plant	Number of chemical applied*									
	1847	1856	1849	1850	1852	1853	1905	1854	1855	1895
Dandelion	64.7	65.5	69.3	58.3	61.9	63.1	——	52.9	47.6	——
Buckhorn	94.1	——	——	72.3	75.0	——	100.0	——	——	81.2
Broad-leaved plantain	100.0	100.0	100.0	100.0	100.0	100.0	100.0	50.0	50.0	95.0

*See list of chemicals, page 437.

of weeds, namely, dandelion, buckhorn, and broad-leaved plantain. The number of weeds ranged from 100 to 750 plants per 100 square feet. All results were obtained by making plant counts.

The data in Table 2 indicate that the heavier oils, represented by Nos. 1854 and 1855, were less toxic than the lighter oils represented by the other numbers; that the oils with furfural added were slightly more toxic; and that dandelion plants were more resistant to treatment than buckhorn and broad-leaved plantain.

Tests with these different materials during the season indicated that a larger percentage of the plants were killed during late June and July when the temperature was high and the soil moisture low than by similar applications made during August and September when there was more moisture and the temperature was lower. No difference was observed in the number of plants killed on different plats treated at different times during the day.

Greenhouse tests.—In order to study under controlled conditions the effect of different amounts of material applied, several series of the various species of lawn weed plants were transplanted into jars, placed in a greenhouse, and treated. Treatment consisted of different chemicals and different amounts of each chemical.

Results indicated that the amount of material necessary to kill any plant varied greatly with the size of the plant (4). Large dandelion plants, with roots 18 inches long, required over 3 times more material of the same strength to kill them than did seedling plants.

Further tests were made in order to study the rapidity of kill of the different materials. For this purpose dandelion plants with a leaf spread of approximately 4 inches in diameter were transplanted into jars and placed in a greenhouse where they were allowed to grow for 3 weeks and then treated (Fig. 1).

FIG. 1.—Three mature dandelion plants which were the same size before treatment. A, no treatment; B, 12 days after treatment with 1 cc of Stanolex Fuel Oil No. 3 plus 15% furfural; and C, same as B except 8 cc were used instead of 1 cc.

The data in Table 3 indicate that when furfural is added to the petroleum oils they become more rapid weed killers (5). Preliminary tests indicated that heavy oils represented by formulas Nos. 1853 and 1854 were slower to kill the plants than were the lighter oils represented by formulas Nos. 1847 and 1852, even when no furfural was added.

TABLE 3.—*Percentage of plants killed after different intervals of time following treatment with 2 cc of various chemicals.*

Chemical	Days after treatment		
	Two	Five	Seven
Fuel Oil No. 1 (No. 1847)	33	50	66
Fuel Oil No. 1 plus 10% furfural (No. 1850)	66	Dead	Dead
Fuel Oil No. 3 plus 15% furfural (No. 1905)	Dead	Dead	Dead

BROADCAST METHOD (3)

Results are reported on two kinds of field weeds treated by the broadcast method, namely, quack grass and field bindweed. Plats were established in areas where a dense growth of the species of weed to be treated was the only kind of vegetation present. Before treatment practically all plants were alive and the above ground growth was green. In this condition the plats were estimated to contain 100% living plants. Following treatment, the amount of injury was determined by estimating the percentage of the plat area which contained brown-colored, injured, and dead-appearing plants. The figure obtained was used to designate the percentage of top growth dead as a result of the treatment. The term "top growth dead" is used because the chemicals did not kill the roots of the plants. Consequently, after an interval of time following treatment, new growth replaced the dead top growth and the area again contained a dense green covering of the species of weed.

The data in Table 4 indicate that applications of 500 and 750 gallons per acre of the lighter oils were sufficient to kill most of the above ground growth of quack grass and field bindweed. Applications of 250 gallons per acre were less effective. The apparent injury from the treatments was in all cases reduced by new growth at the end of 6 weeks time. Observations made on the treated plats the following season indicated that there was very little, if any, difference between treated and control plats. The heavier oils, represented in Table 4 by Nos. 1854 and 1855, were not so effective in killing top growth as were the other materials.

A number of the plats for which data are given in Table 4 were retreated later in the season (October 14) with the same amounts of the same materials as were used in the first treatment. A sufficient number of plants survived this second treatment to produce a new heavy growth of weeds when observed 1 year later.

TABLE 4.—*Percentage of top growth dead at intervals after applying varied amounts of different furfural-petroleum materials on July 19, 1932.*

Treatment No.	Gallons per acre	Date observed and weed treated					
		August 1		August 18		October 7	
		Quack grass	Bind-weed	Quack grass	Bind-weed	Quack grass	Bind-weed
1847	250	90	100	60	15	30	0
	500	90	100	80	20	65	0
	750	90	100	100	30	90	0
1849	250	70	100	50	10	10	0
	500	85	100	85	10	50	0
	750	90	100	90	30	80	0
1850	250	70	100	50	15	10	0
	500	90	100	85	20	55	0
	750	100	100	100	30	80	0
1852	250	80	100	75	40	10	0
	500	90	100	80	55	45	20
	750	90	100	90	75	75	20
1853	250	75	100	70	35	20	10
	500	100	100	90	55	60	20
	750	100	100	95	70	90	25
1854	250	50	40	30	30	40	0
	500	70	50	60	40	40	0
	750	80	70	80	70	50	0
1855	250	50	50	30	20	5	0
	500	75	65	65	40	35	0
	750	85	90	85	65	60	0
1856	250	70	100	50	10	10	0
	500	90	100	80	25	35	0
	750	100	100	95	30	80	0

SUMMARY

Approximately 70% of the dandelion plants growing on plats where the grass was kept cut short were killed by one application of 4 cc of the best furfural-petroleum materials. Observations indicated that large mature plants required more material to kill them than did small plants. Some plants killed 3 inches below the crown produced new growth which appeared above ground 42 days following treatment.

A 100% kill was obtained when broad-leaved plantain plants were treated with 4 cc of the best materials.

A 100% kill was obtained with buckhorn plants treated with 4 cc per plant of the best materials. Smaller amounts were less effective.

One application of 250, 500, or 750 gallons per acre of any of the materials did not kill all the roots of either quack grass or field bindweed. A second application on the same plats with the same quantity as applied the first time did not give complete eradication.

Late June and July treatments gave a higher percentage of kill than late August and September treatments. Here, moisture was one of the most important factors involved.

No relationship was found to exist between the time of day when application was made and the resulting percentage of kill.

When added to petroleum oils, furfural increased their toxicity, causing them to kill with greater rapidity.

The lighter grade petroleum oils were in all cases more toxic than heavier grade oils.

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SHALL CROPS BE ADAPTED TO SOILS OR SOILS TO CROPS?[1]

E. N. FERGUS[2]

ALL efforts to obtain profitable production in farm crops involve either improving the adaptation of crops to environment or improving environment for the crop. Probably most farmers practice mainly one or the other, but few follow one to the exclusion of the other. There are many ways in which farm crops can be adapted to environment, as, for example, by varietal improvement, choice of seed, seeding practices, choice of crop to suit soil type, etc., but none is more generally followed nor more potent for good or evil to civilization than selection of crops to suit the soil's productive capacity. Environmental adaptation, likewise, is brought about in several ways; for example, by cultivation, drainage, irrigation, manuring, liming, and applying commercial fertilizers. Undoubtedly, the practices of the latter group that most affect the well-being of society over a long period are manuring, liming, and fertilizing.

To the farmer on a highly productive and relatively inexhaustible soil, the difference between farm practices based upon adapting soil to crop, on the one hand, and those based upon adapting crop to soil, on the other, is likely to be largely academic. But to society the difference is critical because any soil farmed for several generations according to one of these practices will ultimately differ widely in productivity from a similar soil on which the other method of farming has been practiced. Most, if not all, countries of northern Europe practice an agriculture based upon soil adaptation, whereas large sections of China and India may be considered to have emphasized crop adaptation as their basic agricultural practice even though they have endeavored to conserve the mineral resources of their soils.

The advantages of a system of crop production based upon principles of building soil productivity to suit crops are familiar to all agronomists and therefore need not be discussed. Probably all agronomists are more or less aware, also, that the practice of selecting crops adapted to successive degrees of soil depletion will eventually exhaust the soil and bring agriculture to ruin, but as a group we have said little about it. Had we been greatly concerned about the outcome of the practice, perhaps there would be much less need for the present effort at rehabilitation and resettlement. Instead of hailing the "poorland clover" and the "poor man's alfalfa," we should point out the danger such adaptations imply.

The phenomenal rise of the annual lespedezas to a prominent place among the crops of a large area of the United States has crystallized rather than introduced the problem of the final result of a system

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of farming based on selecting crops to suit a soil's decreasing fertility. It seems unlikely that anyone familiar with the history of the expansion of the lespedeza acreage will deny that the lespedezas have become so extensively grown largely because they are adapted to depleted soils, rather than because of their several quite desirable qualities, such as ease and economy of establishing stands, heavy yields of forage and seed, drought resistance, etc. Unwittingly, therefore, most farmers are actually impoverishing their land still farther after it has become too poor for other crops.

The outcome of this practice of choosing poor-land crops to suit a soil as it becomes impoverished, unattended by liming, manuring, and fertilizing, is certain to have serious consequences. For example, red clover once regularly produced excellent crops on land in Kentucky on which even adapted varieties will not now grow without lime and phosphorus. Instead of applying these materials to the soil, farmers use crops adapted to poorer soil. Redtop, orchard grass, and especially lespedeza are used. They require less calcium and phosphorus than clover, and lespedeza, at least, also seems able to obtain appreciable amounts unavailable to clover and other crops. Consequently, it seems that sooner or later the supplies of calcium, phosphorus, and other essential elements must become so much reduced that they are no longer sufficient even for lespedeza. There are areas in which this condition apparently has been reached already.

Again, poor-land crops, when grown on poor soil, yield crops of low quality. They are frequently very weedy, especially the forage crops. No crop so far discovered has quite equaled certain weeds in adaptability to poor soil. But more serious is the low quality of the crop itself. It reflects the poverty of the soil on which it grew. For example, the phosphorus content of lespedeza hay produced on poor soil in Kentucky varies from 0.1 to 0.17%, whereas all-legume hay produced on our best soils contains from 0.22 to 0.4%.[3] The protein content of the hay is in general proportional to the phosphorus content, which agrees with Orr's (8)[4] observation that forage deficient in minerals usually is also low in protein.

The significance of the low nutrient content of the poor-land crops becomes apparent when the many reported instances of malnutrition of animals that have been traced to mineral-deficient forage are considered. Most of these have been reviewed by Orr, and all are pertinent to the question of the nutritional value of poor-land crops, but especial significance is found in the results of studies of malnutrition of native cattle on native ranges in Florida (1, 2).

It will be recalled that two types of malnutrition were found in the slow-growing native herds, one caused by a deficiency of calcium in the forage, the other by a deficiency of phosphorus. The actual difference between the composition of the herbage on the affected and the healthy ranges was small; for example, the phosphorus content was, respectively, 0.082 and 0.133%.

These results possess even more meaning if considered along with such malnutrition studies as those made in Wisconsin (4) and in

[3]From analyses made by Department of Feed Control.
[4]Figures in parenthesis refer to "Literature Cited," p. 446.

Minnesota (3), which show that livestock in those states received insufficient amounts of phosphorus from crops containing from 0.09 to 0.19%. These grades of stock apparently required at least 0.3% in contrast to the 0.13% required by the native cattle of Florida. The Minnesota report expresses the opinion that the optimum phosphorus content of rations for cattle is about 0.4% on a dry-matter basis.

Grades of livestock, therefore, vary in their mineral requirements; poor grades being able to obtain their needs from herbages of low content, whereas high grades require feeds of high content. The known variation in minimum phosphorus requirement in forage, for example, is from 0.13 to 0.3%. Perhaps there are types of animals that can grow and be healthy on less than the lower figure, and it is more likely that some highly developed kinds require more than the higher figure. Most livestock in the United States is more or less improved and therefore has an intermediate minimum requirement. It is likely that most of this stock requires at least 0.2% of phosphorus which is 0.03% higher than the richest in phosphorus of the previously mentioned lespedeza hays grown on the poorer soils of Kentucky. A grade of livestock that obtains an insufficient amount of a mineral in its feed must evolve into a poorer grade unless the deficiency is corrected by some form of supplementary feeding. Undoubtedly, all agronomists will agree that it is better to increase the mineral content of the forage and other feeds by soil improvement.

The low nutritive value of poor-land crops grown on poor soil has a still more serious aspect, however. The human being is just as much dependent upon his food for minerals as the lower animals. Therefore, it is to be suspected that mineral malnutrition must likewise occur in peoples dependent upon food grown upon impoverished soil for their sustenance. While information pertaining to human malnutrition that may be ascribed to this cause is meager, there is enough to indicate that it exists in serious proportions. According to Maxwell (6), osteomalacia is common in women living in northern China and Manchuria. Many of the cases are caused by a deficiency of calcium in the native food plants (7), i. e., crops adapted to soils that are now deficient in minerals because of the long practice of a system of farming that has not provided for the return of minerals to the soil in amounts equal to those removed in crops (5). The manifestations of the disease were identical with those of the same disease in the native cattle of Florida, namely, as a skeletel breakdown most common in females that had borne offspring.

It seems highly improbable that such a disease could develop in humans in this country, outside of isolated areas, because much of our food is obtained from widely separated regions, some of which have soil of satisfactory mineral content. Nevertheless, the readiness and even enthusiasm with which our American farmers have received poor-land crops, together with their rather general indifference toward soil building and conservation, fill all but the least imaginative with some feeling of apprehension for the future.

In conclusion, it should be emphasized that while a system of farming based principally upon growing poor-land crops appears

wholly unsound as a permanent agricultural practice, it must not be assumed that its limited utilization is to be condemned. There are large areas of eroded and worn-out land on which growing poor-land crops while building them into productive soils is a practice well suited to the requirements, resources, and abilities of the farmers on them. Farmers on the less productive soils of Kentucky are unanimous in the belief that without soil treatments lespedeza in a rotation increases the yield of the grain crops from 15 to 30%. There is reason to agree with them even though we have made no effort to ascertain its effect apart from liming or fertilizing, or both. However, lespedeza in a rotation with corn and wheat on each of which 300 pounds of 16% superphosphate were applied increased the corn yield 17.0% and the wheat yield 48.7% over a 6-year period. Soybeans instead of lespedeza decreased the yield of corn 0.7% and increased the wheat yield 26.8%. Cowpeas had practically the same effect as soybeans.

However, agronomists assume a grave responsibility in recommending even limited use of poor-land crops, at least on poor soils. The practice is so easy to follow that the farmer will continue it until both he and his soil are impoverished beyond redemption by his own resources. Therefore, while it may appear at times to be our duty to recommend crops suited to poor soils, it is even more our duty to point out the consequences of the improper use of this system of farming and to insist that unless it contributes permanently to soil building it is unprofitable to the farmer and to society.

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NATIVE GRASS BEHAVIOR AS AFFECTED BY PERIODIC CLIPPING[1]

W. B. GERNERT[2]

THE plant cover of native grasslands, commonly known in America as "The Prairie," is now being recognized as offering a very substantial foundation for solving the many crop and erosion control problems so enigmatically confronting this generation. With the extensive agricultural reconstruction activities in the Mississippi Valley, a great demand has arisen for more grass and soil cover. There are many who remember the tall, luxuriant bluestems, panic, Indian, and similar grasses which flourished in the eastern section of the prairies. These grasses were followed by bounteous crops for a number of years after they were plowed under. The writer can well remember personally burning off 80 acres of such grass—tall enough to get lost in—in order that he might "break" the sod more readily.

The material used in the study here reported was supplied by a virgin grass clipping project which has been under way at the Oklahoma Agricultural Experiment Station during the past 6 years. The present report deals with a special study of 12 of the 96 plats in comparison with the idle roadside and a pastured area with regard to certain perturbing questions which have become prominent and vital to a more complete understanding and clearer vision in the continuation of the project and to further research in this field.

THE SITUATION

The area under observation was restricted to a fenced and staked series of 96 small plats of native grass, each 8 by 12 feet in size; together with the surrounding, moderately grazed native pasture from which these plats were fenced off 6 years previously, and the unmolested strip of identical origin along the adjoining roadside. The location is an east exposure of a sloping hillside having a drop of 5 feet in 100, and on that vast area of lands known as the "Red Plains."

The soil of the area studied is identified by the U. S. Bureau of Soils (3)[3] as "Kirkland loam," originating in the Permian rocks of the Carboniferous age. It is described as being "brown in color rather than red—probably due to the long period of time during which it has been subjected to weathering, a soil in an advanced stage of development, with a—friable surface horizon and a rather well-developed granular structure and a low content of carbonates." This particular area discloses a rather compact, brownish-red, sandy subsoil beginning at varying depths of from 8 to 15 inches. Typical Kirkland loam has the following physical components:

	Sand, %	*Silt, %*	*Clay, %*
Surface	43.2	40.9	15.9
Subsurface	30.6	43.7	25.7

[1]Contribution from the Agronomy Department, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Also presented at the Annual Meeting of the Society held at Chicago, Ill., December 5 and 6, 1935. Received for publication March 18, 1936.

[2]Associate Professor.

[3]Figures in parenthesis refer to "Literature Cited," p. 455.

THE CLIMATE

Rapid changes in temperature, moisture, and air movement are characteristic of the area, although the climate is preponderantly mild and pleasant. The mean annual temperature is 59.4° F, but readings of 110° have occurred with 55 consecutive days in 1934 reaching 100° or more. There have been 7 years recorded when the temperature did not mount to 100°. Scorching hot winds may accompany high temperatures. Both the coldest (—18°) and the warmest (90° F) winter temperatures have been registered in the month of February.

The average for the seven warmer months is above 70° and that of the five colder months, November to March, inclusive, above 40° F. The normal growing season for native grass is approximately 200 days, with the average date of first and last killing frosts approximately November 1 and April 1. Prevailing winds are from the south with north winds in December, January, and February. Air movements are most vigorous in March and April.

Local precipitation averages nearly 34 inches annually, with extremes of 16.79 inches in 1914 and 61.1 inches in 1908, both of which years preceeded the present investigation. Fortunately, the greater amounts of rainfall occur during the growing season, with the greatest monthly rain in May and the more torrential rains in the fall. Snows are usually light and of short duration. The effectiveness of the 34-inch precipitation is depreciated by a free surface water evaporation of more than twice as much, usually above 80 inches annually during the months of March to early November, inclusive, when water is not frozen. Atmospheric humidity is correspondingly low.

VEGETATION

The local grasses are typical of the region and the wide belt extending north and south from Canada to the Gulf through the eastern parts of the prairie states. Maps of native vegetation in the Mississippi Valley show three types of grasslands, *viz.*, bunch (tall grass), mat (short grass), and range (sparse vegetation). The virgin prairies of the Ohio, Wabash, and Illinois rivers were formerly occupied by somewhat similar vegetation. In order of dominance, the local unmolested grasses along the alleys of the plats and the roadside are as follows:

Little bluestem	(*Andropogon scoparius*)
Switch grass	(*Panicum virgatum*)
Indian grass	(*Sorghastrum nutans*)
Big bluestem	(*Andropogon furcatus*)
Blue grama	(*Bouteloua gracilis*)
Side-oat grama	(*Bouteloua curtipendula*)
Needlegrasses	(*Stipa* sp.)
Prairie three-awn	(*Aristida oligantha*)
Prairie dropseed	(*Sporobolus*)
Paspalums	(*P. stramineum*, *P. tradescantia*, and others)

The surrounding region of native grass is commonly referred to as "bluestem" or "tall grass" country.

IDENTIFICATION OF THE 14 GRASS PLATS

NO TREATMENT

B1 = No treatment, not clipped, check.
D10 = No treatment, not clipped, check.
Pasture = Pastured continuously since before 1890 (50 years). Controlled and grazed only by cattle since 1928. Mowed spring and fall. (96 plats fenced off in it in 1930.)
Roadside = Narrow, unclipped strip, 10 feet wide adjoining, with a deep ditch between the road and strip. (Rapid drainage.)
B3 = Clipped 6 years 2 times each year, on July 20 and Nov. 2.
C4 = Clipped 6 years 3 times annually, May 18, July 20, and Sept. 21.
D8 = Clipped 6 years 5 times, May 18, June 29, Aug. 10, Sept. 21, Nov. 2.
E6 = Clipped 6 years 8 times, beginning May 25 and at 21 day intervals until Oct. 19.
F9 = Clipped 6 years 9 times, May 18 to Nov. 2.
F6 = Clipped 6 years 10 times, April 27 to Nov. 2.

TREATED

(Manure and fertilizer were applied only once at the beginning of the experiment, clipped 6 years)

G3 = 10 tons of stable manure and 400 lbs. superphosphate (20% P_2O_5) per acre. Clipped 5 times, May 18, June 29, Aug. 10, Sept. 21, Nov. 2.
H3 = Same treatment as G3, clipped 2 times, July 20, Nov. 2.
G4 = 100 lbs. sodium nitrate ($NaNO_3$) per acre. Clipped 5 times, May 18, June 29, Aug. 10, Sept. 21, Nov. 2.
H4 = Same treatment as G4, clipped 2 times, July 20, Nov. 2.

The areas were selected to represent distinct types of clipping and no clipping, continuous pasture, and limited treatment with manure, phosphate, and nitrate of soda. The following points were studied: total clippings (5 years), comparative production (5th year), root weight (6th year), root volume (6th year), weight-volume factor, soil moisture (3 horizons, 6th year), soil organic matter (3 horizons, 6th year), soil pH (3 horizons, 6th year), sod slices mounted for study (3 horizons, 6th year), continuous controlled pasture, and unclipped and untreated.

RESULTS

Table 1 presents a summary of the observations made on the above-mentioned points.

On the basis of air-dry hay or clippings (secured with a hand sickle) and oven-dried weights with 15% added uniformly to all for "air dry" moisture, the "Air dry" figures are similar to farmer's hay production weights. Production of the 5th year shows that not enough additional yield is gained by 3 to 5 clippings to pay for the labor. Eight to 10 clippings annually produced much less total yield than 2 clippings. On the fertilized plats, two clippings produced considerably more than five clippings on similar plats.

Ellet and Carrier (5) conclude that on permanent bluegrass, "the total yield of dry matter varies inversely with the number of times the grass is cut during the growing season." Aldus (1) restates the same conclusion on prairie grass in Kansas. He also cites Crozier (4)

TABLE 1.—*Native grass reactions in Payne County, North Central Oklahoma.*

Plat No.	Clippings per year (6 years)	Tons air-dry hay per acre, 1934 (5th year)	Root weight in grams per cylinder, 4⅛ × 5 in.	Root volume in cc per cylinder, 4⅛ × 5 in.	Weight/volume factor	Soil moisture %			Organic matter %			Soil pH		
						1–3 inches	6–9 inches	12–15 inches	1–3 inches	6–9 inches	12–15 inches	1–3 inches	6–9 inches	12–15 inches
B-3	2	1.02	11.2	21	0.5333	15.67	16.24	14.87	7.25	3.85	4.00	6.19	6.17	5.99
C-4	3	1.36	10.0	18	0.5559	15.66	14.26	16.02	5.70	4.15	2.90	5.94	6.28	6.19
D-8	5	1.22	13.4	34	0.3941	16.45	12.96	20.09	7.25	3.48	2.00	6.07	6.61	7.61
E-6	8	0.82	5.9	12	0.4916	15.91	13.80	10.80	7.60	3.70	3.60	5.97	6.09	6.31
F-9	9	0.92	5.5	13	0.4230	16.63	13.54	13.08	7.10	4.75	3.20	6.19	5.90	6.03
F-6	10	0.92	4.9	12	0.4083	16.06	14.62	11.66	7.90	3.80	3.80	5.99	6.09	6.10
G-3 MP	5	1.12	6.9	17	0.4058	17.07	11.44	16.05	6.95	4.40	3.80	6.02	6.51	6.78
H-3 MP	2	1.65	13.3	23	0.5782	17.74	15.89	14.70	9.80	4.45	4.15	6.30	6.35	6.62
G-4 N	5	1.26	6.0	10	0.6000	16.47	15.74	14.83	9.80	4.00	3.30	6.10	6.30	6.48
H-4 N	2	1.38	9.8	17	0.5764	17.37	13.38	17.25	7.70	4.45	3.90	6.16	6.12	6.36
B-1 check	0	0	13.2	22	0.6000	14.74	14.73	22.25	8.20	4.30	4.00	5.99	6.14	5.97
D-10 check	0	0	5.7	9	0.6333	13.24	14.18	18.13	7.40	3.70	2.90	6.28	6.45	6.87
Pasture	?	?	3.6	7	0.5142	16.82	14.14	14.96	7.00	3.90	3.10	6.28	5.97	6.36
Roadside	0	0	19.6	31	0.6322	16.54	18.69	16.30	5.40	4.50	3.80	6.28	6.10	6.07
Average			9.21	17.6	0.5247	16.16	14.54	15.83	7.50	4.10	3.46	6.13	6.22	6.41

finding similar results on cultivated grasses. Weaver and Fitzpatrick (10) state, "Practically all of the prairies have been mowed annually, some for a period of more than 50 years. It has been repeatedly demonstrated that removal of the plant cover after it is mature has no harmful effect upon the vegetation." This is a point to which grass students might well give further scrutiny.

To avoid disturbing a large area of the tiny 8 by 12 foot plats, a small "standard" sod sampling tool was used with a plunger for removing sods 4⅛ inches in diameter and 5 inches deep. Identical and representative sods were thus taken from each of 14 situations. The above-ground vegetation, together with all plant residue, was shaved off at the surface of the soil cylinders which were then placed in gallon cans of water 24 hours to soften the soil. The sample mass was washed into a 20-mesh screen where the washing of the roots was finished with a power spray. After drying till surface water was no longer visible, the last soil particles were removed by hand picking.

Root volume was determined by placing these roots, free of external water, in a dry, graduated cylinder of 250-cc capacity. A previously measured quantity of water (150 cc) was then poured over the root mass. The increased reading gave the root volume by subtraction. The graduate was bounced on the table to remove all visible air bubbles.

Plat D8, which had been clipped 30 times in 6 years, produced the greatest root volume, the roadside second, and one of the manure and phosphate treated plats third. The pasture sample returned the lowest yield of roots by volume, considerably lower than the plats clipped 8, 9, and 10 times.

After the volume was taken, the roots were dried 2 days in an electric oven at 110° C. Since no accepted factor for the average water content of air-dry native grass roots is available, the weights in grams were recorded on a water-free basis. Root weight is correlated with above-ground production evidently, but shows much greater variation. The roadside root sample produced much the greatest weight but not the greatest volume. The pasture sample was lowest of all in weight and one of the check plats which was not clipped for 6 years was also very low, showing that a long period of time may be required for the recuperation of underground grass parts.

Results by Weaver and Harmon (9) indicate that more than half of the roots of vigorous grasses may be found in the upper 4 inches of soil. In the present investigation with impoverished grasses, considerably more than three-fourths the total root mass was obtained in the upper 5 inches as was indicated by examination of the deeper horizon before the hole was filled to facilitate resodding. (See Fig. 1.)

It is significant that root volume expressed in cubic centimeters shows greater production and variation than does root weight in grams. This might indicate grams to be the coarser measure. That this is not due to choice of measurement units but rather to variability in root structure, which is indicative of vigor and activity, is evident. The average root volume in cubic centimeters at the bottom of the table is approximately twice that of root weight in grams.

FIG. 1.—Native sod panels. Panels 20 × 3 × 8 inches deep were removed while the soil was moist, washed carefully, and mounted in their relative position and distribution. Plats clipped less frequently, fertilized, or left uncut exhibit the more dense and heavier growth of both root and above-ground vegetation. These sod sections were secured just before the time of the last clip of the season, Nov. 2.

The combined values of root weight and root volume expressed in a weight-volume factor affords an opportunity to study the two simultaneously. It is possible that this factor is a more dependable evaluation of root development. The grass plats showing the greatest above-ground growth yield the large root weight-volume factors with but few exceptions. (See Fig. 1.)

Soil moisture at three depths, 1 to 3 inches, 6 to 9 inches, and 12 to 15 inches, was obtained by removing tube-core samples of soil $1\frac{5}{16}$ inches in diameter, drying them 2 days in a 110° C electric oven and weighing direct in grams. Surface soil moisture on November 16 was higher on frequently clipped plats and on the pasture than on those clipped less often, also approximately 2% higher than on the two check plats.

While the rainfall run-off would be greater, undoubtedly, on the plats more nearly bare, the possible rain interception by the plants of the taller growing grasses would alone account for the difference in surface soil moisture of the plats. Horton (6) has shown that plants may intercept from 25 to 100% of light rains which never reach the soil underneath. He found that narrow-leafed and narrow-stemmed plants, such as grasses and evergreen trees, caught a far greater proportion of rain than did the broader-leaved trees, shrubs, and herbs. The possibilities of rainfall interception are indicated by the plat samples shown in Fig. 1.

Moisture at the 6 to 9 inch soil depth was decidedly less than surface soil moisture in the frequently clipped plats, approximately equal in the two checks and highest in the roadside sample. The average of 6 to 9 inch soil depth moisture was 1.62% less than the surface soil horizon moisture and 1.29% less than the moisture in the 12 to 15 inch horizon. Soil moisture in the 12 to 15 inch horizon was intermediate between that of the surface and the second horizon. The greatest amount (22.25%) was found in one of the unclipped plats and in the deepest horizon.

A total of 19 inches of rain fell from July 18 to November 15, with six rains exceeding 1 inch in amount in the season (1935) in which these tests were made. Total rainfall at Stillwater for the year was 33.59 inches, one-third of which fell in the month of June.

Organic matter was determined by the Schollenberger method (7) with duplicate samples obtained at the various depths and by the same method as that used for soil moisture samples. Half of the composite sample was used for organic matter determination and half for pH determination.

Weaver and Harmon (9), say, "Fortunately, the disappearance of dead organic matter from the soil is very slow, and even in bared soil it may remain during a long period of years." On the other hand, sod is reputed to be one of the most rapid contributors to soil organic matter, and increased organic matter has been called (2) the "byproduct of good farming." On old fields which have been cultivated many years, with or without the addition of chemical fertilizers, the soil becomes sad and tight, sticky when wet and is very difficult to cultivate.

If the loss of organic matter is slow, as stated, the rapid degeneration of occupied soils must be due to the organic matter condition rather than amount, but quoting again, "The amount of organic matter largely determines the productive power of the soil" in arid as well as humid regions. The rapidity with which favorable organic matter content of soils is regained by means of grass and legume culture is also stated in the literature (8).

As shown in Table 1, the organic matter content in the lower horizon of the frequently clipped plats was less than that of the least frequently clipped plats, but one of the check plats was also low. By way of possible illumination, this plat and horizon is highest in pH. Organic matter diminished nearly one half on the average on all plats in the deepest horizon. The high surface horizon readings obtained from two fertilized plats, H3 and G4, may have been caused by root response to fertilizer, although two similarly treated plats failed to equal the high figure. Apparently, soil organic matter and live root weight and volume are not necessarily directly correlated, nor does it appear that live roots use up any considerable quantity of the soil organic matter.

The quinhydrone (electrolitic) method was used for determination of pH. The remaining half of the composite sample used for organic matter determination was available for this work. Based on the theory that soil acidity is due largely to crop removal and accompanying decrease in calcium, together with other alkaline salt removal, we might expect that the roadside area and the two check plats which had not been clipped during the past 6 years would show a relatively higher pH. One of the plats receiving manure and phosphate 6 years previously but clipped only twice annually was slightly highest in pH, with the roadside, pasture, and one of the check plats following closely. The lower readings were obtained on the untreated plat clipped 3 times, on those clipped 8 times and 10 times, and on one of the checks which was high in organic matter in the upper horizon.

In the 6 to 9 inch soil horizon the highest pH reading was found in the plat with the lowest organic matter content, C4. The lowest pH in this zone was found on the plat with the highest organic matter content and the next to the highest clipping frequency, F9. The pasture exhibited the second lowest pH.

Both the lowest and the highest pH of the 12 to 15 inch horizon were found on the two unclipped (check) plats and the next two highest on the plats receiving manure and phosphate. The second lowest pH was found on plat B3, clipped twice annually. The horizon averages increased with the depth and inversely with decrease in organic matter, as is to be expected in this climate and soil.

SUMMARY

1. Clipping native grass more than twice annually did not return enough additional production in the fifth year to pay for the labor. As the number of clippings increased, production declined.

2. The greatest yield of air-dry hay was obtained from the plat clipped twice and treated with barnyard manure 6 years previously at the rate of 10 tons with 400 pounds of 20% phosphate per acre.

3. The least top weight was secured from plats clipped 8, 9, and 10 times annually.

4. The greatest root weight was obtained from the unmolested roadside grass and the next greatest root weight from an untreated plat clipped five times annually, from one plat clipped only twice annually but receiving an initial treatment of manure and phosphorus, and from one of the check plats.

5. The lowest production of roots by weight came from plats clipped most frequently and which also produced the least top weight.

6. The greatest root volume was obtained from the plats exhibiting greatest root weight.

7. The lowest root volume was found on the pastured area, on one of the check plats, on the manured plat, and on the plat clipped 10 times annually.

8. The roadside, check, and nitrated plats and one manured plat produced the highest root weight-volume factor.

9. Lower root weight-volume factors were obtained on those areas clipped more frequently.

10. Soil moisture was greatest on unclipped plats and larger in the various horizons on plats less frequently clipped. For the average of the 14 plats the 1 to 3 inch horizon contained the most soil moisture, the 12 to 15 inch horizon ranked second, and the 6 to 9 inch horizon third in the sixth year.

11. The lowest soil moisture in the upper horizon was found in the unclipped plats; in the second horizon, curiously, in one of the plats receiving manure and phosphate; and in the third horizon, in the most frequently clipped plats, as would be expected.

12. Soil organic matter was greatest in the upper horizons and in one of the plats receiving manure and phosphate, in one of the plats receiving $NaNO_3$, and in one of the unclipped plats.

13. Low soil organic matter was not always found where expected and is apparently not associated with the amount of live roots. If soil organic matter content is quite permanently residual, it must be the result of previous vegetative growth.

14. The pH was highest in the upper horizon on plats manured and phosphated but clipped only twice annually. It was also high on unclipped, pastured, and roadside plats, but was highest in the lower (12 to 15 inch) horizon of plats clipped five times, one of which received manure and phosphate. An unclipped plat was also high. The lower horizon produced the highest average pH readings.

15. The lowest pH reading was found in the 6 to 9 inch soil horizon of a plat clipped nine times annually. Other low pH readings were distributed through the various horizons.

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KINGWA SOYBEANS[1]

R. J. GARBER[2]

A NEW pure-line variety of soybeans developed on the agronomy farm of the West Virginia Agricultural Experiment Station is described and named Pekwa in Bulletin 247 of that Station issued in 1932. On the last page of the bulletin mention is made in a footnote of another pure-line selection also developed at the West Virginia Agricultural Experiment Station and named Kingwa. These new varieties, which are practically indistinguishable, came from individual plant selections of the commercial Peking variety. The purpose of this paper is to present evidence that makes it seem desirable to substitute the name Kingwa for Pekwa and to discontinue distribution of the strain now grown under the name of Kingwa.

Since the above-mentioned bulletin was published, Kingwa has become well established in southern Indiana and the seed of this variety is handled by commercial seedsmen. The acreage in Pekwa, on the other hand, is confined largely to certain sections in West Virginia and the seed of this variety is not so well established in the seed trade. A brief history of the introduction of Kingwa into Indiana may be of interest.

Seed of the two pure-line selections, I–21–7 (later named Pekwa) and I–21–8 (later named Kingwa), was exhibited in the "Better Crops Exhibit" by West Virginia University in 1927 at the International Grain and Hay Show held at Chicago, Illinois. M. O. Pence, extension agronomist of Purdue University, obtained seed of I–21–8 and turned it over to the Agronomy Department of the Indiana Experiment Station for testing. In 1928 the variety was included in the soybean variety trials at Lafayette, and in 1929 the seed stock was increased. In the spring of 1930, 2 bushels of Kingwa were supplied to Henry L. Hahn, a farmer near Evansville, Indiana. In 1931, 200 bushels of his crop were certified and since then the acreage of Kingwa has steadily increased in southern Indiana. In some areas Kingwa is the only variety of soybeans that is grown at present.

In the comparative yield trials of Pekwa and Kingwa at Morgantown, W. Va., carried on for a period of 12 years, no significant difference in yielding ability either of hay or seed has been found between these varieties. The average annual yields as determined in rod-row plats replicated four or five times are shown in Table 1.

It is apparent from the data presented in Table 1 that Pekwa and Kingwa do not differ significantly in yielding ability of either hay or seed when grown under conditions that obtain on the agronomy farm near Morgantown, W. Va.

The same two strains of soybeans have been grown in comparable variety trials during a period of 4 years by the Purdue Agricultural

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TABLE 1.—*Average yields of seed in bushels per acre and of hay in tons per acre of Pekwa and Kingwa soybeans grown during a period of 12 years in comparative two-row plats near Morgantown, W. Va.*

Variety	Average annual yields per acre												Grand av.
							Seed in Bushels						
Pekwa	37.8	20.3	25.3	20.3	21.3	28.3	17.3	32.7	27.6	18.0	17.3	26.6	24.4
Kingwa	36.8	20.5	24.2	22.9	20.8	29.2	18.1	31.1	30.7	18.5	16.0	26.1	24.6
							Hay in Tons						
Pekwa	2.82	2.16	2.49	2.01	2.33	1.75	1.49	2.20	1.99	1.57	1.73	1.72	2.02
Kingwa	2.90	2.40	2.16	2.08	2.27	1.89	1.38	2.15	2.37	1.53	1.60	1.70	2.04

Experiment Station at Lafayette, Indiana. The seed and hay yields which were kindly furnished to the writer by R. R. Mulvey are shown in Table 2. The data from Indiana corroborate those obtained in West Virginia in showing no significant difference in yielding ability between Pekwa and Kingwa.

TABLE 2.—*Average yields of seed in bushels per acre and of hay in tons per acre of Pekwa and Kingwa soybeans grown during a period of 4 years in comparable plats near Lafayette, Ind.*

Variety	Average annual yields per acre				Grand av.
		Seed in Bushels			
Pekwa	38.9	25.0	25.6	35.9	31.4
Kingwa	36.2	24.9	25.0	33.7	30.0
		Hay in Tons			
Pekwa	3.25	1.85	1.90	3.09	2.52
Kingwa	3.04	1.88	1.95	3.15	2.50

At the Ohio Agricultural Experiment Station Pekwa and Kingwa have been compared during 2 years. The yield data collected in these tests and kindly furnished by J. B. Park of that station indicate no significant difference between the two varieties.

The data presented above, together with other similar data, show conclusively that Pekwa and Kingwa are very similar in yielding ability. There is also a striking resemblance between the two varieties with respect to other characteristics. Both have marked ability to retain their leaves even after the pods are ripe; both have relatively fine stems and an erect growth habit, although Pekwa is inclined to be somewhat more erect than is Kingwa. Kingwa is perhaps a few days later in maturing, is somewhat less uniform, and has slightly smaller seeds than Pekwa. It is extremely difficult if not impossible to distinguish these two varieties when growing side by side.

At the time (1931) Pekwa was named and was being distributed in West Virginia, Kingwa was being increased in southern Indiana. Owing largely to the fact that the latter region includes a relatively extensive soybean growing area, whereas the area devoted to this crop in West Virginia is rather small and scattered, Kingwa has increased more rapidly than has Pekwa. In fact, Kingwa has become quite well established in commercial channels, while Pekwa is known chiefly in West Virginia.[3]

Soybean growing areas other than those in Indiana and West Virginia are considering growing one of these two varieties and inasmuch as the two are so similar, it seems unwise to continue to distribute both of them and attempt to maintain their purity, particularly where they are grown near one another in the same region.

At a recent meeting of agronomists representing the states concerned, it was proposed to continue to increase and distribute only one of these two strains and to adopt the name *Kingwa* because it is commercially established. Inasmuch as selection I–21–7 (the strain at present grown under the name of Pekwa) is more uniform and has a somewhat more erect habit of growth than selection I–21–8 (the strain at present grown under the name Kingwa), it was suggested that henceforth selection I–21–7 only be increased and distributed under the name Kingwa. There is not enough difference between the two strains to justify carrying both under two names, so the above suggestions have been accepted by the West Virginia Agricultural Experiment Station. *The pure line selection I–21–7 made from the Peking variety and formerly named Pekwa is hereby renamed Kingwa and, at the proper time, application for registration under this name will be made.*

[3]At the time selection I–21–7 was named Pekwa by the West Virginia Agricultural Experiment Station it was expected that selection I–21–8 would be suppressed. However, the latter had already established a satisfactory record in southern Indiana and selection I–21–7 was unknown to that region. As a result of this situation, and at the suggestion of K. E. Beeson, extension agronomist of Indiana, selection I–21–8 was named Kingwa as mentioned previously.

PREDICTION OF DOUBLE CROSS YIELDS IN CORN[1]

C. W. DOXTATOR AND I. J. JOHNSON[2]

WHEN four satisfactory inbred lines of corn are to be used in a double cross, it is necessary to know how these can be combined to obtain the best possible double cross.

Jenkins,[3] in estimating the probable performance of double crosses, concluded that inbred-variety crosses were advantageous in the selection of inbred lines which will combine best in double crosses. Another of the methods of estimation used was to determine the combining ability of four of the six single crosses which can be produced by the crossing of four inbred lines in all possible combinations. Obviously, in the hybridization of two single crosses, the parent single cross combinations are not involved in the yield of the double cross. It is, therefore, theoretically possible to obtain three different yielding double crosses from four inbred lines by the use of different single cross parents. For example, the expected yield of a double cross (a × b) (c × d) is obtained from the average yield of the four single crosses a × c, a × d, b × c, and b × d. If the yields of the six single cross combinations from four inbred lines are different, the expected yield of the three possible double crosses will also be different. Although the inbred variety cross appears to be a desirable method of selecting inbred lines for use in double crosses, single cross data from any four selected lines should therefore be of value in determining which of the three possible double crosses are most productive.

The data herein reported were obtained in 1935 at University Southeast Branch Experiment Station, Waseca, and at University Farm, St. Paul, Minn. At the Waseca station four inbred lines, cultures 11, 14, 374, and 375, which are being used in a double cross and are in convergent improvement studies, were available in the six single and three double cross combinations. Two three-way crosses were also available. Cultures 11 and 14 are inbreds of medium early Minn. 13 and cultures 374 and 375 are inbreds of yellow corn and are extremely late in maturity. From previous tests for several years these inbreds were known to have desirable combining ability. The 11 crosses and a check hybrid were grown in six replicates of three-row plats. Only three stalk hills in uniform competition were harvested and in no case was a yield figure based on less than 10 hills. The mean yields of the crosses and the analysis of variance for the experiment are given in Table 1.

In the study made at University Farm, four double crosses from Northwestern Dent inbred lines were grown together with the single crosses needed for the prediction of their yields. The crosses were planned so as to determine the yields obtained from two double

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[2]Instructor and Assistant Professor, respectively.

[3]JENKINS, MERLE T. Methods of estimating the performance of double crosses in corn. Jour. Amer. Soc. Agron., 26:199–204. 1934.

TABLE 1.—*Yields and analysis of variance of six single, three double, and two three-way crosses from four inbred lines of corn.*

Key	Hybrid	Yield in bus. per acre	Hybrid	Yield in bus. per acre
(A)	11×14	56.98	(11×14) (374×375)	78.70
(B)	11×374	88.67	(11×374) (14×375)	66.33
(C)	11×375	88.87	(11×375) (14×374)	70.58
(D)	14×374	85.18	(11×14) 374	81.67
(E)	14×375	79.48	(11×14) 375	82.83
(F)	374×375	52.13	Minhybrid 301	83.02

Source of variation	D.F.	Sum of squares	Mean square	F	Standard error of mean
Blocks....	5	64.84	12.968		
Crosses....	11	9,667.98	878.907	70.12	
Error.....	55	689.37	12.534		1.45
Total .	71	10,422.19			

crosses made between different single cross parents from the same four inbred lines. Two such comparisons are available. Six replicates of each cross were planted in single-row plats. Only three stalk hills surrounded by hills of corn were harvested for yield. The yields of the single crosses, the four double crosses, and of standard Northwestern Dent are given in Table 2.

TABLE 2.—*Average yields in bushels per acre of the single crosses used in the prediction of double cross yields and the yields of four double crosses between them.*

Key	Hybrid	Yield in bushels per acre	Key	Hybrid	Yield in bushels per acre
(G)	62×64	31.4	(N)	66×68	62.1
(H)	62×66	58.8	(O)	67×68	38.8
(I)	62×67	28.5	—	(62×66) (67×68)	41.8
(J)	62×68	17.1	—	(62×67) (66×68)	48.4
(K)	64×66	48.6	—	(64×66) (62×68)	54.1
(L)	64×68	37.7	—	(64×68) (62×66)	44.5
(M)	66×67	58.9	—	N. W. Dent	50.1

Standard error of the mean = 1.60 bu.

In predicting the yields of the double crosses, the yields of the four single crosses not used as parents were averaged. The predicted yields of the three-way crosses were based on the average yield obtained from the two single crosses made between the two inbred lines used in the single cross and the inbred line used as the male parent in the three-way cross. In Table 3 are given the actual yields of the double and three-way crosses, together with the predicted yields based on the single cross yields used in their prediction.

In the results from the Waseca station, the double cross (11 × 14) (374 × 375) yielded 12.37 bushels higher than (11 × 374) (14 × 375) and 8.12 bushels higher than (11 × 375) (14 × 374). These differences are highly significant. By the use of the appropriate single crosses for prediction of yields, a very good agreement to the actual

yields has been obtained. The combination (11 × 14) (374 × 375) has been selected as the most desirable. The predicted yields of the two three-way crosses were even greater than for the most promising double cross. The experimental results from these three-way crosses are in accord with the prediction.

TABLE 3.—*Actual and predicted yields of double and three-way crosses.*

Hybrid	Yield in bus. per acre		Single crosses averaged for predicted yields
	Obtained	Predicted	
	Waseca Branch Station		
(11×14) (374×375)	78.70	85.55	B, C, D, E
(11×374) (14×375)	66.33	70.79	A, C, D, F
(11×375) (14×374)	70.58	69.31	A, B, E, F
(11×14) 374	81.67	86.92	B, D
(11×14) 375	82.83	84.17	C, E
	University Farm		
(62×67) (66×68)	48.4	43.4	H, J, M, O
(62×66) (67×68)	41.8	41.7	I, J, M, N
(64×66) (62×68)	54.1	47.5	G, L, H, N
(64×68) (62×66)	44.5	39.8	G, K, J, N

The yields of the two Northwestern Dent double crosses (62 × 67) (66 × 68) and (62 × 66) (67 × 68) made between different single cross parents from the same four inbred lines should have been different on the basis of their predicted yield, the greater yield being expected from the former. Actually, the crosses differed by 6.6 bushels per acre, a highly significant difference in accord with the prediction.

Similarly, the yields of the two double crosses (64 × 66) (62 × 68) and (64 × 68) (62 × 66) made from the same four inbred lines differ in their predicted and actual yields. With these two double crosses, the yields obtained differed by 9.6 bushels per acre. The odds for the significance of these differences exceeds 99:1.

SUMMARY

From the results obtained in these experiments it appears that highly significant differences in yielding ability can be found in double crosses resulting from the use of different single cross parents produced from four inbred lines. The results obtained also indicate that by the appropriate use of single cross data, the highest yielding double cross combination may be predicted.

HUMIDITY CONTROL IN LARGE CHAMBERS BY MEANS OF SULFURIC ACID SOLUTIONS[1]

Frank J. Zink and C. O. Grandfield[2]

THE need of controlling humidity along with temperature control in relation to two problems under investigation, *viz.*, the influence of atmospheric humidity on the rate of drying of alfalfa and the effect of humidity on the seed setting of alfalfa plants, resulted in the construction of a simple and accurate method which is described herein as a guide to other investigators confronted with a similar need.

As the necessary equipment was not available, search of the literature on humidity control was made to find some reference to an inexpensive method to meet the requirements. Most of the methods of obtaining variable humidity control with spray jets for humidifying and refrigerating systems for dehumidifying are commercial units built largely for air conditioning of buildings and do not permit a sufficiently accurate control within the range suitable for research work.

Satisfactory humidity control by means of supersaturated salt solutions is reported by Spencer (1)[3] and a number of other investigators. Each salt used provides for only one condition of humidity, rather than a range of conditions. In other investigations humidity control has been obtained by aqueous solutions of sulfuric acid (2). By varying the concentration of the acid, any desired degree of humidity may be obtained. The majority of these studies used sulfuric acid with desiccators or other small enclosed chambers (3). Zink (4) used sulfuric acid in desiccators for this purpose in studies of equilibrium moistures of hays.

From the experience of using acid in desiccators and information on the specific limit of size of enclosed space found in the literature, it seemed possible to enlarge the space conditioned and to increase the quantity of acid in a ratio similar to that used in desiccators to a point where large cabinets might be used. The basic method has been reported on by Wilson (5) who gives a graph and states the thermodynamic theory of the calculation.

In the studies reported in this paper the first efforts were confined to bubbling air through acid solutions of different specific gravity and directing the conditioned air into an enclosed space of approximately 5 cubic feet. This means has served for small bulbous glass chambers and possibly would serve for a chamber of larger size if a good diffusion of air and acid could be obtained, or if large volumes of acid could be used in a closed chamber. The variable results obtained

[1]Contribution No. 69 from the Department of Agricultural Engineering and No. 258 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication April 1, 1936.

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[3]Figures in parenthesis refer to "Literature Cited," p. 466.

were attributed to condensation of moisture in the tubing leading to the chamber and also to the fact that the specific gravity of the acid was changed constantly through the loss or addition of moisture.

Following these trials, glass dishes similar to photographer's developing trays were used in the chambers. A number of these containers could be used, thereby regulating the amount of acid surface exposed. The acid exposed in trays served much better for humidity control than the bubbling method. After a few hours of control, however, the formation of a scum or a stratification of the surface apparently occurred and some agitation of the acid was necessary to reestablish diffusion. A small fan was placed in the chamber for this purpose and gave satisfactory results.

Based on the experiences obtained in the small experimental cabinet, two larger cabinets, one containing 9 cubic feet of air space and the other 56 cubic feet, were designed to fit the problems for which the work was intended. Any desired relative humidity could be obtained by using acid of the required specific gravity. The specific gravity is measured with hydrometers ranging from 1.000 to 2.000, reading to 0.002. Only a small original supply of acid is necessary as it can be used repeatedly. When different densities are desired, the acid, before placing it in the cabinet, may be diluted by adding water or concentrated by evaporating water from it by using dry air. Small fans were used to increase the molecular absorption and diffusion of the surface of the acid and to prevent stratification on the surface.

RESULTS

The results obtained are shown in Figs. 1 and 2 and are considered highly satisfactory. Periods of accurate control varied in length from a few hours to 10 days. The range of humidity control was from near 0 to 90% at temperatures varying from 50 to 110° F. Reference to the basic diagram of Wilson (5) indicates that any desired humidity condition may be obtained over a range of temperatures from 0 to 75° C. The range of constant humidity control may be seen from the graphic records.

Fig. 1 shows two charts from a hygro-thermograph in the small cabinet, covering a period of 48 hours. Charts A and B illustrate the control of humidity by means of sulfuric acid under different degrees of temperature and rates of temperature fluctuation. Where the temperature as shown in chart A was lowered abruptly from 95° to 85° F, the humidity without control would have risen temporarily, but by dehumidifying with dry air from a low temperature chamber the humidity was held to a relatively straight line. As shown in chart B, under gradual changes in temperature of not too wide range, the humidity is not affected.

Fig. 2 shows charts A and B obtained in the large cabinet under different ranges of temperature and humidity than those shown in Fig. 1. In chart B the relative humidity was changed by the addition of water to the acid. In approximately 2 hours, the relative humidity was established at the new level. This chart was made when samples were being removed from the cabinet at intervals and consequently shows a saw-tooth effect.

There are a number of limitations of the method, which if understood and considered in the design of the apparatus for its application, need not interfere with its uses. For example if the materials under observation give up or absorb much water, this water has to be absorbed by or given up by the acid solution. Such exchanges alter the specific gravity of the acid and hence set up different conditions. If the samples are small and only a small amount of moisture is to be absorbed or released by the acid no appreciable change in hu-

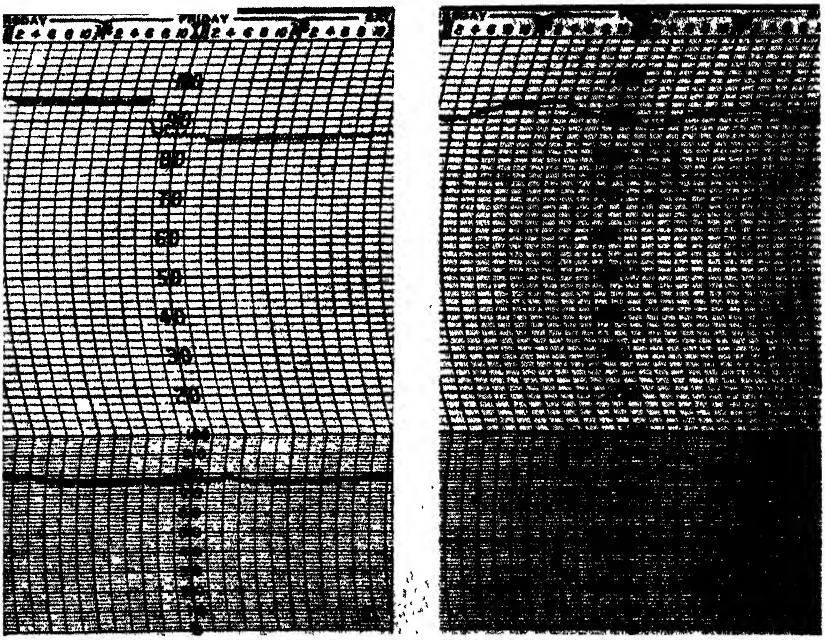

FIG. 1.—Hygro-thermograph records of 48 hours duration, showing humidity control in a 9 cu. ft. cabinet. Upper line temperature; lower line humidity.

midity will occur. In the study of the drying rate of alfalfa, samples of 50 stalks did not change the specific gravity of the acid solution. If larger samples were to be used, the volume of acid should be increased accordingly. If this were done, no appreciable change in the specific gravity of the solution would occur and suitable constant humidity conditions would be maintained. However, with growing plants, it was necessary to dehumidify during the middle of the day because of the different rates of respiration between night and day. The respiration during a part of the day was faster than the moisture from the air would diffuse with the acid. This was taken care of by dehumidifying with dry air from the outside if sufficiently low in humidity or from a low temperature chamber for the lower humidities.

From the results obtained in this work it is apparent that, with limitations, if understood, the use of sulfuric acid as a means of hu-

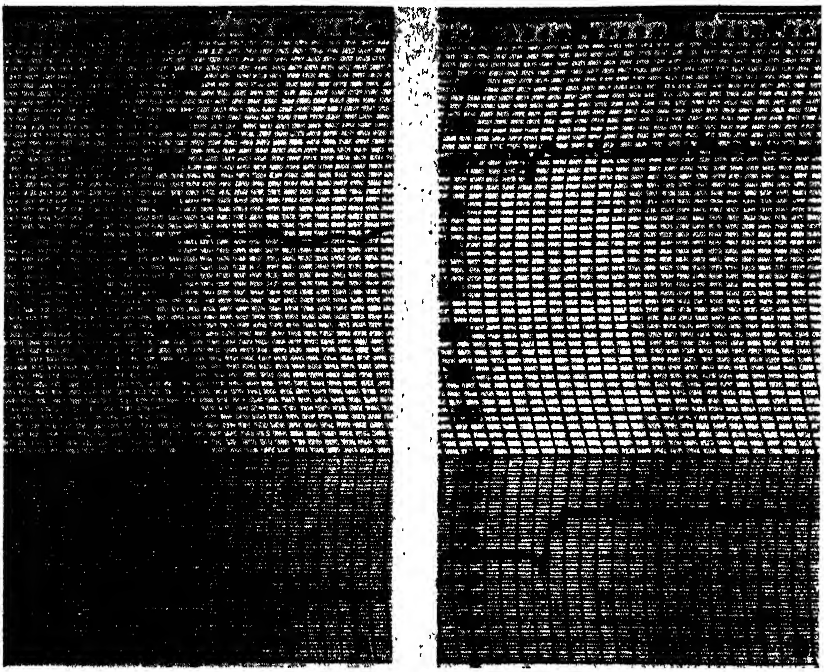

FIG. 2.—Hygro-thermograph records of 48 hours duration, showing humidity control in a 56 cu. ft. cabinet. Upper line temperature; lower line humidity.

midity control is satisfactory in conducting agricultural research of certain types. This method of control has the advantage of low cost, simplicity, and accuracy under temperature controlled conditions. More extensive work should develop convenient equipment for many problems.

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INHERITANCE OF RESISTANCE TO *USTILAGO LEVIS* (K & S) MAGN. (COVERED SMUT) IN A CROSS BETWEEN MARKTON AND COLORADO 37 OATS[1]

W. W. AUSTIN AND D. W. ROBERTSON[2]

COVERED smut caused by *Ustilago levis* (K & S) Magn. is responsible to a large degree for the heavy yearly losses in yield suffered by many farmers throughout the irrigated section of Colorado. This is especially true where the farmer does not use a chemical seed treatment for control.

The problem of breeding for resistance to smut in oats and the manner of inheritance has been studied by a number of investigators. Difficulty has been experienced by most workers in obtaining a satisfactory epidemic in the field. This condition, along with the existence of several physiologic forms, has complicated the problem of determining the number and nature of genetic factors involved.

The purpose of this investigation was to study the mode of inheritance of *Ustilago levis* in a cross between Markton and Colorado 37 oats, and to attempt to produce true-breeding, smut-resistant strains having the desirable characters of both parents.

REVIEW OF LITERATURE

The inheritance of resistance to smut in oats has been studied by several workers. Wakabayashi (12)[3] published the first report in this country on inheritance of smut resistance in oats. He worked with Red Rustproof, which is resistant to covered smut, and Black Tartarian, which is susceptible. He concluded several genetic factors were involved and that resistance was dominant.

Barney (1), working with Turkish Rustproof × Gold Rain, Swedish Select × Burt, and Fulghum × Black Mesdag, concluded smut resistance was controlled by one, two, and three independent factors, respectively.

Reed (8) found resistance dominant to susceptibility in a cross between Black Mesdag and Hull-less. He also (9) studied the inheritance of resistance to smut infection and found the segregation in the F_2 apparently to be on the basis of a single factor difference.

Gaines (3), working with Markton as the resistant parent, states that it probably contains three factors for smut resistance.

Hayes, Griffee, Stevenson, and Lunden (5), working with a cross between a homozygous strain (White Russian × Minota) Minnesota No. 11-18-37 and Black Mesdag, state that there are separate factors which differentiate immunity and resistance, respectively, located in Black Mesdag. The factor pair II might be considered to be epistatic to the factor pair RR. A mixture of both smuts was used in this study.

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[3]Figures in parenthesis refer to "Literature Cited", p. 471.

Garber, Giddings, and Hoover (4) studied the inheritance of smut infection in the cross Gopher × Black Mesdag. Gopher is moderately susceptible to both loose and covered smuts and Black Mesdag is immune. It was found they differ in their reaction to smut infection by a single main factor, and, in addition, by at least one modifying factor which resulted in transgressive segregation for susceptibility. They suggest that I might act as an inhibitor to R, or as an additional factor for resistance but less potent than R.

Welsh (11) studied the cross Victory × (Minota-White Russian × Black Mesdag) and found evidence of transgressive segregation in families inoculated with loose and covered smuts. The results indicate that at least two factors govern the inheritance of smut reaction in this cross.

Coffman, *et al.* (2) studied crosses between Markton and several common oat varieties. They state the results obtained from this study give reason to doubt the existence in Markton of three factors for resistance to all *Ustilago levis* strains. Transgressive segregation was observed; however, they were unable to make a factorial genetic analysis of their data.

Stanton, Reed, and Coffman (10) infected a Markton × Black Mesdag cross with *Ustilago avenae*. Both parents were infected with the same smut before planting. No smutty plants developed; however, a marked infection did develop in the F_3 progenies. This might be explained, they say, by the presence of complementary factors for susceptibility, which when brought together through hybridization may produce infected plants.

Johnson (6), working with a Black Mesdag × Victory cross, concluded that a two-factor difference existed between the parents, Black Mesdag possessing the dominant factors and Victory the recessive allelomorph of these factors.

MATERIALS AND METHODS

Markton (C. I. No. 2053), which has been found highly resistant to both species of smuts by several workers, was used as the resistant parent. Colorado 37 (C. I. No. 1640), a high-yielding, thin-hulled, midseason oat of Swedish type, was used as the susceptible parent.

In the spring of 1931, crosses were made between the above-named varieties. Three F_1 plants were produced from the cross Colorado 37 × Markton. Only one plant was produced from the reciprocal cross. All F_1 plants were of the Markton type. The F_1 plants were threshed and dehulled as described by Reed (7). The inoculum used in smutting the F_1's was collected from a field of Colorado 37 growing at the Colorado Experiment Station. The smut was identified as *Ustilago levis*. The inoculum was prepared by grinding the smutted panicles and sifting the ground material through a fine sieve. A germination test was made on the collection and the smut spores were found to be approximately 90% viable. Inoculations were made by placing a liberal amount of inoculum in each envelope with the dehulled seed and shaking vigorously. The seed was then space-planted 2 or 3 inches apart in 18-foot rows. Two hundred seeds of each parent were also dehulled, smutted, and planted. In the fall all the plants were pulled, counted for smut, and threshed separately.

One hundred seeds from each plant were dehulled and smutted during the winter. The following spring, the F_2 seeds were planted in 8-foot rows. Seed of each parent was dehulled, inoculated with smut, and check-rows planted at 25-row intervals along with the F_3's.

EXPERIMENTAL DATA

At time of heading, segregation for plant type and color was noticed in the F_2 families. No attempt was made, however, to obtain counts on these characters. Out of the 484 seeds from F_1 plants, 12 failed to emerge and 9 plants developed smut. There are several factors or combinations of factors which might have prevented the germination of these 12 F_1 seeds, such as mechanical injury caused in dehulling, destruction by insects, or the lethal effect of the smut organism on the young susceptible seedlings. Since it was impossible to determine which factors were responsible, it was decided to analyze the data in two ways; first, by considering the 12 seedlings as susceptible and adding them to the infected class; and, second, by assuming that mechanical or insect injury was the cause of their failure to emerge. Tables 1 and 2 present the results obtained.

TABLE 1.—*F_2 segregation for smut resistance in a Colorado 37 × Markton Cross.**

	No. of plants not infected	No. of plants infected	Total	D/P.E.
Observed	463.00	21.00	484	—
Calculated 63:1	476.38	7.62	484	7.4
Calculated 15:1	453.75	30.25	484	2.6

*The 12 seedlings that failed to emerge were considered as infected.

TABLE 2.—*F_2 segregation for smut resistance in a Colorado 37 × Markton cross.**

	No. of plants not infected	No. of plants infected	Total	D/P.E.
Observed	463.00	9.00	472	—
Calculated 63:1	464.82	7.18	472	1.0
Calculated 15:1	442.50	29.50	472	5.8

*The 12 seedlings that failed to emerge not taken into account.

In Table 1 a very good fit to a calculated 15:1 ratio was obtained and a very poor fit to a calculated 63:1 ratio. In Table 2 just the opposite was true. Due to these conflicting results, no definite conclusion can be drawn from the F_2 data.

Table 3 presents the results obtained by classifying the F_2 plants by use of the F_3 reactions to smut inoculation. Smut counts were made on each row and the rows later grouped into classes according to the percentage infection. A class interval of 5% was used in grouping the F_3 rows. If the data are grouped into two classes, infected and non-infected, it is shown (Table 4) that a good fit to a 9:7 ratio is obtained. Assuming that three independent factor pairs were responsible for resistance, a poor fit to a 27:37 ratio was obtained.

TABLE 3.—*Distribution of F_2 based on F_3 data of the Colorado 37 × Markton cross.*

	Percentage smut arranged in class intervals of 5%																					Total
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
											Colorado 37 × Markton											
No.	269	113	38	13	14	5	3	3	1	3	1	–	–	–	–	–	–	–	2	4	3	472
%	57	24	8	3	3	1	0.6	0.6	0.2	0.2	0.2	–	–	–	–	–	–	–	0.2	1.2	0.6	100
											Colorado 37											
No.	–	–	–	–	–	–	–	–	–	–	1	3	1	1	3	4	–	2	–	2	2	19
%	–	–	–	–	–	–	–	–	–	–	5	16	5	5	16	20	–	11	–	11	11	100
											Markton											
No.	19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	—
%	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	—

TABLE 4.—*F_3 segregation for smut resistance in a Colorado 37 × Markton cross and test of goodness of fit to a 27:37 and a 9:7 ratio.**

	No. of plants not infected	No. of plants infected	Total	D/P.E.
Observed	269.0	203.0	472	—
Calculated 27:37	199.5	272.5	472	9.60
Calculated 9:7	265.5	206.5	472	0.48

*12 F_3 seeds not taken into account.

The results obtained from the F_3 data indicate the presence of two dominant factors for resistance in the Markton parent.

SUMMARY

Markton (C. I. No. 2053), found to be resistant to a mixture of covered smut found at the Colorado State College Experiment Station, was used as the resistant parent. Colorado 37 (C. I. No. 1640), found to be susceptible to a mixture of the same smut, was used as the susceptible parent due to its yielding ability and other desirable characteristics.

The inoculum used was collected from a field of Colorado 37 growing at the Colorado Experiment Station, Fort Collins, Colo. The smut was identified as *Ustilago levis* (K & S) Magn.

All seeds used in the study were dehulled and smutted.

The F_2 results were erratic and no conclusions could be drawn from them without further study.

The F_3 families segregated in the ratio of 9 uninfected to 7 infected. It was concluded that a two-factor difference for smut exists between the parents; Markton possessing the two dominant factors for resistance, while Colorado 37 has the recessive allelomorphs of these factors.

Some very promising, highly resistant lines are being continued in the hope of developing some high-yielding, smut-resistant, commercial strains.

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THE RELATION OF MOISTURE CONTENT AND TIME OF HARVEST TO GERMINATION OF IMMATURE CORN[1]

G. F. SPRAGUE[2]

THE satisfactory and efficient use of the greenhouse in corn breeding and genetic investigation requires that the planting of the winter crop be delayed as long as possible and still permit the maturing of seed before the time of spring planting. Thus, for greenhouse-grown corn, planting usually follows very closely after harvest. Under such conditions corn sometimes exhibits slow and irregular germination. In rare cases a complete failure to germinate is noted. The possibility of poor or irregular germination appeared to be one factor limiting the usefulness of the greenhouse in advancing breeding and genetic investigations.

Under certain conditions small grains have a marked period of dormancy. It was thought that the occasional poor germination of greenhouse-grown corn might be a manifestation of the same phenomenon. These studies were undertaken to determine the importance of after-ripening in corn and, if possible, to find some method of hastening the process.

The germination and subsequent growth of prematurely harvested but thoroughly after-ripened corn has been studied by Robinson[3]. The literature on dormancy and after-ripening has been reviewed by Harrington[4] and no further review will be presented here. For the small grains in general he concludes that the embryo is not dormant, dormancy being imposed by an impermeable seed coat.

MATERIALS AND METHODS

In preliminary comparisons of greenhouse- and field-grown corn there was no evidence of any difference in germination response when corn of equivalent stages of development and maturity was compared. For this reason, all subsequent studies were carried out with field-grown corn since it was more readily available and could be obtained in any desired quantities.

Double and single crosses of field corn have been used to insure greater uniformity and thereby reduce the size of sample necessary for adequate representation. Pollinations for periodic sampling were made on a single day to insure material of known age. Three to five ears were harvested at 5-day intervals beginning 10 days after pollination and continuing until immediate normal germination was obtained. The kernels were removed from the ears immediately after harvest, bulked, and spread in a single layer to dry. Samples for moisture, germination, and chemical treatment were taken from the bulked sample.

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[1]The studies herein reported were conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Missouri Agricultural Experiment Station, Columbia, Mo. Received for publication April 3, 1936.

[2]Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

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The moisture samples were dried in an electric oven at 100° C. The germination samples were planted in sand and daily records were made of emergence until germination was thought to be complete. No plantings were discarded until germination was perfect or until examination revealed that the ungerminated seeds had rotted.

EXPERIMENTAL RESULTS

The moisture percentage and dry weight per sample of 20 kernels for the periodic harvests are shown graphically in Fig. 1. The summarized data on germination are presented in Table 1. The moisture percentages range from 83.79 for the first harvest to 23.33 for the last harvest. The percentage of germination for these same samples determined immediately after harvest ranged from 0 to 100. Morphological differentiation does not appear to be a factor in these studies since normal plants were obtained from the first harvest sample.

TABLE 1.—*Effect of time of harvest and moisture content on the amount and variability of germination in field corn.*

Days from		Moisture %	Germination %	Days from planting to	
Pollination to harvest	Harvest to sampling			First emergence	Final emergence
10	0	83.79	0	—	—
	4	76.63	5	19	19
	8	50.63	25	6	12
	12	17.35	50	5	7
21	0	67.42	5	11	13
	3	65.86	35	13	21
	8	45.53	90	3	20
	15	16.04	100	3	6
25	0	60.47	20	16	24
	4	45.14	55	6	22
	11	24.24	90	5	7
30	0	48.13	75	6	17
	6	25.73	100	3	8
	8	19.68	100	3	7
36	0	40.59	70	7	21
	2	33.54	100	3	42
	8	17.97	100	4	6
41	0	31.48	85	6	48
	4	26.34	100	3	12
	9	13.29	100	4	6
45	0	29.39	75	6	38
	5	21.69	100	3	6
50	0	27.25	95	4	36
	5	13.76	100	3	6
55	0	23.33	100	3	5

The relationship between the moisture content and the percentage of germination is quite striking both within and between dates of harvest. The percentage of germination increased rather steadily with increasing maturity and decreasing moisture content of the sample. A high moisture content appears to be associated with a high degree of variability in the time required for germination. This relationship is most striking in material harvested 30 or more days after pollination. Presumably a similar relationship exists in the younger material but is partially obscured by the greater incidence of rotted kernels.

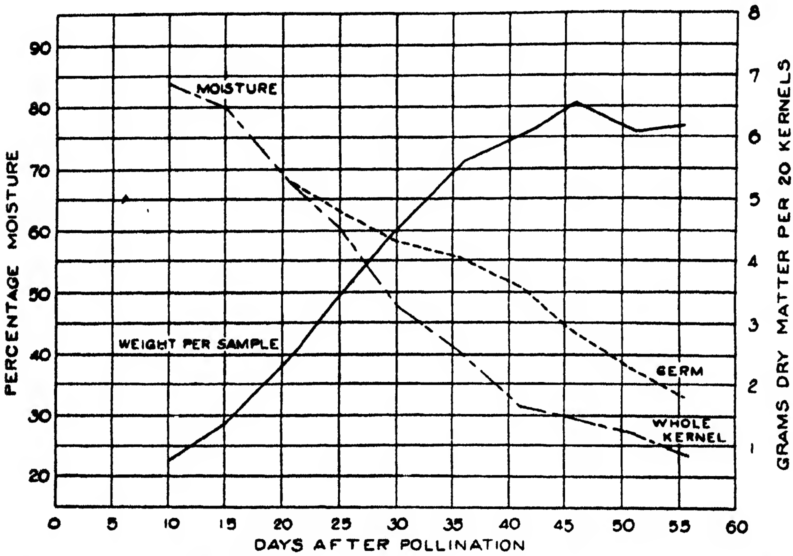

FIG. 1.—Kernel weight and moisture percentage at periodic intervals during development. (Solid and dashed lines represent the whole kernels; dotted lines represents the germs only).

The maximum spread from initial to final emergence for any lot was 42 days. When more completely dried, a second sample from the same harvest dates exhibited a spread in emergence of only 2 days. Tests on thoroughly air-dried and after-ripened corn gave a mean spread in emergence of 2.5 days.

Moisture and germination records on duplicate lots of corn stored in a saturated atmosphere are presented in Table 2. The favorable temperature (80° to 90° F) and the high humidity resulted in such a rapid development of molds that samples could be kept no more than a week. The results indicate, however, that for the short period involved, no appreciable after-ripening occurred. An equal period of storage while exposed to the air was sufficient to produce complete after-ripening. This relationship is very strikingly shown in the 45-day sample in Tables 1 and 2.

The original sample for this date contained 29.39% of moisture, had a germination of 85%, and had a spread of 32 days from initial

to final emergence. After the sample had been allowed to dry for 5 days, the moisture content had decreased to 21.69%, the germination had increased to 100%, and only 3 days elapsed between the emergence of the first and last seedling.

TABLE 2.—*Effect of storage in a saturated atmosphere on the amount and variability of germination in corn.*

Days from		Moisture %	Germination %	Days from planting to	
Pollination to harvest	Harvest to sampling			First emergence	Final emergence
25	0	60.47	55	16	24
	4	61.51	15	7	17
	7	60.96	25	7	10
36	0	40.59	70	7	21
	6	37.62	60	5	15
45	0	29.39	75	6	38
	5	35.89	80	5	46
	10*	16.05	100	4	5

*Removed from saturated atmosphere at the end of 5 days and allowed to air dry for 5 days.

A duplicate lot of the same sample was stored in a nearly saturated atmosphere for 5 days. There was a slight increase in moisture content, from 29.39 to 35.89%, and the variability of germination was slightly increased. When this sample was removed from the saturated atmosphere and allowed to become air dry, the loss in moisture was accompanied by a marked decrease in the variability of the time required for germination.

Various attempts were made to hasten the after-ripening process by means other than drying. Soaking seeds for a 1-hour period in a 1% solution of sodium thiocyanate or a 1.5% solution of hydrogen peroxide was ineffective. The removal of the pericarp and temporary storage under conditions of increased oxygen pressure were also ineffective unless they were accompanied by a loss in water. The results then seem to indicate that there is a strong relationship between the loss of water from immature seeds and their ability to germinate normally.

The data in Tables 1 and 2 indicate that immature samples having more than 25% of moisture will exhibit a reduced percentage of and an increased variability in germination if planted immediately. This is true for all samples, whether freshly harvested or partially dried. This percentage (25) is based on the moisture content for the entire grain. The values for the scutellum and embryo would be somewhat higher as they have a higher moisture content than the endosperm during the later stages of development (Fig. 1).

In view of the relation between the necessary reduction in moisture content and the onset of normal germination in immature corn, it seemed of interest to determine the moisture content necessary for germination.

Starchy and sweet corn seeds were placed, abgerminal side down, on filter paper in a petri dish. The paper was moistened sparingly in the hope that absorption would be so retarded that the seed would germinate when the minimum water requirement had been attained. Seeds were removed from the dish as soon as either the plumule or radicle started to break through the pericarp. They were then separated into embryo and endosperm and moisture percentages determined. The results are presented in Table 3. At the time of germination, the moisture content was higher in the sweet than in the starchy kernels. This difference can be ascribed almost entirely to the endosperm, the moisture content of the two types of embryos being similar.

TABLE 3.—*The moisture content of corn kernels at the time of germination.*

Type of seed	Mean No. of days to germination	Moisture content at time of germination for		
		Endosperm %	Embryo %	Whole kernel %
Starchy......	14.7	31.37±0.26	61.86±0.64	38.02±0.31
Sugary	14.6	40.39±0.33	58.34±1.08	45.35±0.35

In a second experiment, a sample of corn was exposed to a saturated atmosphere in a constant-temperature chamber at 23° C. Samples were removed periodically and separated into embryo and endosperm and the moisture content was determined. The experiment was terminated after 49 days. At the end of this period, the endosperm contained 30.7%, the embryo 61.7%, and the entire kernel 35.4% of moisture. The results are presented graphically in Fig. 2. When the experiment was terminated, the kernels were obviously swollen, but the pericarp was still unbroken. The two experiments are in agreement in indicating that the moisture content necessary for germination is approximately 35 and 60% for whole grain and embryo, respectively.

Immature corn having a similar moisture content germinates poorly and is highly variable. This suggests that some irreversible process must occur during drying so that 60% of water in the embryo of after-ripened seeds plays a physiologically different rôle than the same percentage of water in an immature embryo. The nature of the reaction is unknown, but it is subject to genetic variation. Certain genetic types (premature germination, vivipary) germinate on the ear with a high moisture content (60 to 80%). Some variation in time of germination is apparent, but the variability is markedly less than for immature seeds of the same age removed from the ear and planted. It seems plausible that in strains of corn germinating prematurely, some inhibiting mechanism is lost early, functioning only at high moisture contents. In normal corn this mechanism persists until the water content has been reduced below the minimal requirement for germination through the normal process of ripening.

Genetic evidence is available for one viviparous type which indicates the location of the mechanism normally inhibiting germi-

nation at high moisture contents. An undescribed genetic type of maize, found by F. D. Richey and the writer, is characterized by the presence of a pink to salmon coloration in both endosperm and scutellum. This type is recessive to normal and always germinates on the ear. When outcrossed with white endosperm types, in addition to

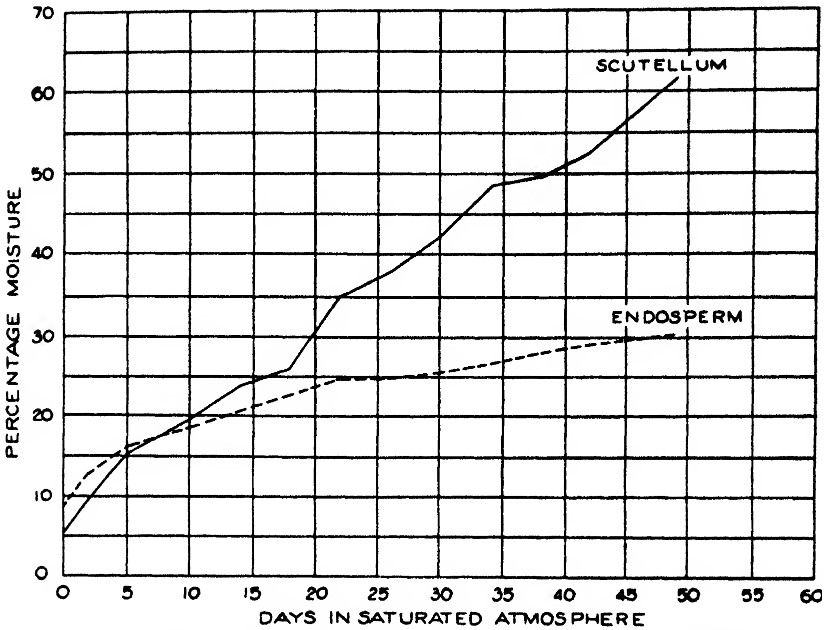

FIG. 2.—The absorption of moisture by corn kernels when stored in a saturated atmosphere.

the expected segregates, two types of hetero-fertilized kernels occurred[5], namely, white endosperm with pink scutellum and pink endosperm with white scutellum. All seeds having pink scutellums, regardless of endosperm color, germinate on the ear. This indicates that the tendency to germinate before dormancy is determined by the scutellum genotype and is independent of the endosperm genotype or of the character of the pericarp. Since the limiting mechanism is hereditary, it must operate in the scutellum rather than in the endosperm.

SUMMARY

After-ripening of immature corn is coincident with the loss of moisture.

Immature corn planted immediately after harvest exhibits great variability in time of germination. With a decrease in moisture content, the percentage of seeds germinating is increased and the variability in time required for complete germination is decreased.

[5]SPRAGUE, G. F. The nature and extent of hetero-fertilization in maize. Genetics, 17:358–368. 1932.

The moisture content of immature seeds must be reduced to approximately 25% before normal germination occurs.

Corn kernels require a minimum of approximately 35 and 60% of moisture in whole grain and embryo, respectively, before germination can occur.

It is suggested that the mechanism which inhibits the normal germination of newly harvested immature corn operates in the scutellum rather than in the endosperm or pericarp.

STUDIES ON HESSIAN FLY INFESTATION AND SOME CHARACTERS OF THE WHEAT CULM[1]

Dean C. Anderson and Hubert M. Brown[2]

A STUDY was begun in 1932 to determine whether there were any significant differences in the amount of Hessian fly, *Phytophaga destructor* Say, injury on the strains of wheats grown on the Michigan Agricultural Experiment Station farm at East Lansing, and, if there were such differences, to determine the relationship between resistance to this fly and breaking strength, weight, diameter of mature culms, and lodging.

Various characteristics of the host plant are said to influence the amount of Hessian fly injury. In brief, these are large coarse straw (7),[3] long ligules which prevent the larvae from reaching the base of the culm and high silica content in cell walls at the base of the plant (3), low ash content in young plants and in mature straw (2), high deposition of cellulose in all walls of crown where larvae begin feeding (4), purple color in straw and genetic characters governing resistance (5), and protoplasmic reaction (6).

MATERIALS AND METHODS

Samples for this study were obtained from the naturally infested wheat nursery by taking a 7-foot section from an outside row of the five-row yield plats from 111 strains of soft winter wheat in 1932 and 112 strains in 1933. Samples from 55 systematically distributed check plats were taken in 1932 and from 52 checks in 1933.

In 1932, 40 to 45 culms from each strain were examined for puparia (flaxseeds). Following the findings of Painter, *et al.* (5), the percentage of infested culms was used as the measure of infestation. Breaking strength, weight, and diameter of culm determinations were made on the center portion of the second internode above the ground. The second internode was used in these determinations because the puparia usually develop on the lower nodes and this internode was of sufficient length to allow the breaking test to be made on it. The diameter of the culm was read from a special V-type caliper and this determination made before further testing. The breaking strength tests were made with the special equipment illustrated in Fig. 1. The force required at the instant of breaking was read from the scale in grams. A 5-cm section of the culm, taken where it had been tested for breaking strength and diameter, was then cut out and weighed on an analytical balance.

In 1933, between 80 and 90 culms from each strain were used in the determinations. Each culm was examined for puparia as in 1932, and those with puparia were placed in one group and those free from puparia in another. Diameter of

[1]Contribution from the Farm Crops Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 261 (New Series). Received for publication April 18, 1936.

[2]Formerly Graduate Assistant in Farm Crops, Michigan State College, now Assistant Agronomist, Colorado Agricultural Experiment Station, Fort Collins, Colo., and Research Assistant in Farm Crops, Michigan Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 483.

culm measurements were not made on this crop. Instead of one culm, two culms were placed on the scale together and their breaking strength determined. As two culms were broken at a time, individual culm weights were not taken, but

FIG. 1.—Apparatus used in determining the breaking strength of one or two wheat culms at a time. The supports on which the straws were placed were 5 cm apart. The lever arm is caused to press on the straws by a screw adjustment. The point of pressure was midway between the supports. The apparatus was designed by W. H. Sheldon, Dept. of Agr. Engineering, Michigan State College.

the number of culms in and the weight of each of the two groups and those culms with puparia and those free from puparia were recorded to allow for the computation of the average weight per two culms.

The lodging notes taken in 1932 were field observations. Five ratings were used in grading from no lodging to complete lodging. No lodging occurred in 1933.

RESULTS

DIFFERENCES BETWEEN STRAINS

Hessian fly infestation.—The fly infestation in the varieties ranged from 7 to 75% in 1932 and from 5 to 75% in 1933. The same strain was lowest both years and was the only strain that had an average infestation of less than 24%, the next lowest 2-year average. There were four strains that had 60% or more infestation each year. The remaining percentages were fairly normally distributed around the yearly means of 38% in 1932 and 47% in 1933. Standard errors calculated from the check rows indicate that strains which differed from each other in infestation percentage by more than 30% in 1932, 27% in 1933, or 20% for a 2-year average, were significantly different from each other. On this basis, it can be seen that there were decided strain differences in degree of infestation.

Breaking strength of culm.—As breaking strength determinations were made on single culms or pairs of culms, it was possible to obtain strain means and their standard errors for use in determining significance of interstrain differences. A difference between strain averages greater than 50 grams in 1932, when single culms were used, and 80 grams in 1933, when two culms were used, was found to be significant. Strain averages ranged from 199 to 530 grams in 1932 and from 408 to 855 grams in 1933. There were significant differences in the average breaking strength between many of the strains in spite of the fact that individual values of these strains over-lapped. This over-lapping of distributions was due, in all probability, in part to variation in shape of culm cross-section and in part to normal variation and indicated that several readings must be made on each variety to obtain a true value.

Weight of culm.—In 1932, the strain mean weights varied from 29 to 58 mg per straw and in 1933 from 52 to 96 mg. Strains differing by more than 6 mg in 1932 and by more than 12 mg in 1933 were, on the basis of standard errors, considered significant. Several of the strains were shown to differ from each other in weight per culm.

Diameter of culm.—This determination was made only in 1932. Strain means and their standard errors were calculated. These mean diameters varied from 2.3 to 3.9 mm and their standard errors indicated that an average difference of 0.3 mm or greater was significant.

Inter-annual correlations.—It has been pointed out in the preceding discussion that many of the strains differed from each other in regard to percentage of fly infestation, breaking strength, and weight of culm. To determine further whether these significant differences were due to environment or heredity, the inter-annual correlation coefficients were calculated. These were for fly-infestation, .30; for breaking strength, .47; and for weight of culm .54. All coefficients are positive and significant, exceeding the Fisher (1) 1% point, and indicate that heredity was playing a part in the observable differences exhibited by the strains.

RELATIONSHIP OF HESSIAN FLY INFESTATION TO CULM CHARACTERS

The discussion thus far has established the point that the strains exhibited to some extent inherent differences in fly infestation and the three culm characters of breaking strength, weight, and diameter of culm. The relationship of Hessian fly infestation to each of these was then determined by means of the simple (total) correlation coefficients which are as follows:

Percentage of fly infestation with	1932	1933
Breaking strength	—.05	—.08
Weight of culm	—.08	—.18
Diameter of culm	—.01	

These coefficients do not exceed Fisher's (1) 5% points and are so small that they indicate that there was no significant relationship between fly infestation and any of the three culm characters.

The data were also studied to determine the effect of fly infestation within a strain upon the culms that were free from puparia and those that were infested. In nearly every strain the puparia-free group average was higher in breaking strength, weight, and diameter than the corresponding puparia-infested group average. Students' method of interpreting paired results was applied and the analysis showed that differences between determinations made on puparia-free straw and those made on puparia-infested straw were significant.

The consistent significant differences found when comparing group averages of puparia-free and puparia-infested material within the same strain seem to be at variance with the low non-significant coefficients of correlation given above. An explanation of these seemingly contradictory results may be that there is no association from strain to strain between Hessian fly infestation, on the one hand, and breaking strength, culm weight, or culm diameter, on the other hand, but when culms are infested with puparia, the result of such an infestation on the individual culm is such that it becomes, on the average, a weaker, lighter, and smaller culm than does a puparia-free culm of the same strain. This explanation tends to be verified further by the consistency in sign of the coefficients of correlation.

As field lodging notes were arranged in only five classes, the coefficient of contingency was used in determining the relationship of this character to fly infestation. The significance of this coefficient was judged by Fisher's (1) Chi-square test. A significant coefficient .46 was obtained and indicates that the greater the fly infestation, the greater the amount of lodging. The presence of the puparia weakens the stem, thus allowing it to break over more readily than uninfested stems would do.

SUMMARY

Strain determinations on percentage of Hessian fly infestation and field lodging and culm determinations on breaking strength, weight, and diameter were made on 111 strains of soft winter wheat in 1932 and 112 strains in 1933. Differences between strains and the differences between puparia-free and puparia-infested groups within the same strain were studied.

There were significant inter-strain differences in fly infestation, breaking strength, weight of culm, and diameter of culm, and these differences, according to inter-annual correlations, tended to persist from year to year.

There were significant differences in breaking strength, weight, and diameter of culm between the puparia-free and puparia-infested groups within the same strain, but the very low non-significant coefficients of correlation between fly infestation and breaking strength, weight, and diameter of culm indicate that selection for fly resistance by using one of these morphological factors would be ineffective.

Hessian fly infestation and field lodging were significantly and positively associated.

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NOTE

THE USE OF RABBITS IN DETERMINING THE PALATABILITY OR TOXICITY OF FORAGE

AS INDICATORS of what might be expected in more valuable animals, rabbits and other small animals have long been used in studies of diseases, nutrition, and methods of inheritance. Only recently, however, have such animals been used as indicators of the palatability or toxicity of plants.

The study of new plants in a forage nursery not only involves the adaptation of the plant to soil and climatic conditions, botanical relationships, and habits of growth, but also the question of their palatability and toxicity must be answered before conclusions can be drawn concerning their value for forage.

When cattle are used to determine the palatability or toxicity of a plant, it is necessary to have the crop growing on a fairly good-sized plot. This may mean 2 or 3 years delay in obtaining sufficient planting material to make a satisfactory test. In the testing gardens located at experiment stations, hundreds of species and varieties of forage plants are often under observation each year. It would be next to impossible to make a satisfactory test of the palatability of each species represented in such a garden if cattle were used as determiners.

The feed eaten by rabbits is similar to that eaten by cattle and if rabbits can be shown to relish the same kind of plants as cattle, their use in palatability tests would have the following advantages: First, a lower initial cost. Second, their shorter growth period makes it possible to obtain comparable data in much less time. Third, the amount of food required for rabbits is much less than for large animals. The use of rabbits would make it possible, therefore, to obtain preliminary information concerning the toxicity and palatability of a new introduction or of a possible new hybrid within the first year of its growth.

The Florida Agricultural Experiment Station, cooperating with the U. S. Department of Agriculture, has a forage nursery of this type in which several hundred plantings, mostly introductions, are under observation. Many of the plants are of a type that only small quantities of herbage are available any one year, and there is need of a method for testing the palatability and toxicity of these on a small scale.

In the summer of 1931 the Florida Station conducted a palatability test of nine species of crotalaria growing together in one field. Cattle were turned into the field and allowed to graze wherever they wished. The relative palatability of the different species was determined by making daily measurements of the length of rows of each species which had been grazed. Thus it was possible to rank the species in the order of their palatability and to assign a satisfactory score to each. A different lot of cattle was used for each of three periods during the season.

A parallel palatability test was conducted with white New Zealand rabbits on the same species. The crotalaria was cut daily and each species, tied in separate bundles, was placed in individual hutches

where the rabbits had free access to all bundles. The relative palatability of the species was then determined by the amount of material eaten from each bundle. Considerable variation occurred in the ranking of the species as determined by the different lots of cattle and by rabbits. In general, however, the rank as determined by the cattle and the rabbits was very similar.

Hay was made from each of eight species and fed to both cattle and rabbits in a palatability test. The hay for both groups of animals was taken from the same source in order to insure uniformity of the material fed to each animal. The relative palatability of the eight species was determined by ranking them on the basis of the amount of each species contained. With two exceptions the ranking of the species by the cattle and by the rabbits was the same. In each of the two exceptions, the amount of hay consumed was so nearly the same that a slight difference in the consumption of either would have changed the rank.

The results led to the belief that rabbits could be safely used to indicate the palatability of newly introduced plants of which we know little, or nothing. A colony of white New Zealand rabbits was therefore established in connection with the forage crop nurseries at Gainesville, to be used as indicators of the palatability and toxicity of the new plants.

Two methods of feeding the plant material are practiced, namely, hutch feeding and actual grazing of plots. In instances where the plant material was limited, samples of the plant under consideration were cut and placed in the hutch where the animals had access to it. The grazing method has been used when sufficient plant material is available. It is accomplished by the use of small movable pens which are placed over a portion of the plants to be tested and the rabbits allowed to graze at will. Grazing has proved to be more desirable in that the rabbits have a tendency to select their food naturally and there is less danger of forced feeding which tends to interfere with the obtaining of satisfactory information.

A few instances will illustrate that the results from the grazing tests have been very satisfactory. Rabbits when placed on plots of the grass *Arundenella echlonii* refused to graze at first. After they had become hungry they ate it reluctantly. Cattle when placed on a plot in which *A. echlonii* was growing with other grasses left it until the other grasses had been consumed, then grazed it sparingly. Rabbits refused molasses grass (*Melinis minutiflora*) for the first day or two after being placed on a plot, after which time they ate it well. The experiment station at Chinsegut Hill Sanctuary report that cattle ate molasses grass very sparingly at first but after the first few days grazed it readily. Rabbits relished *Pennisetum complanatum*, a coarse grass growing in the nursery garden at Gainesville. The West Florida Experiment Station reports that a bull which had been turned onto a plot growing a mixture of grasses, one of which was *P. complanatum*, grazed this species before eating the other grasses. Rabbits and cattle alike relish the *Digitaria* sp. known as Woolly Finger grass. Similar results have been obtained with other grasses and legumes to which both cattle and rabbits have had access.

It is realized of course that the results with rabbits must be considered only as indicative of what may be expected of cattle and that the final decision should be based on tests with cattle. The results, however, have been so consistent that decisions regarding the palatability or toxicity of certain plants are made during the first and second year of test with considerable confidence and on this basis some are discarded and others retained for further testing.—GEO. E. RITCHEY, *Florida Agricultural Experiment Station, Gainesville, Fla.*

BOOK REVIEWS

SOILS: THEIR ORIGIN, CONSTITUTION, AND CLASSIFICATION

By G. W. Robinson. London: Thomas Murby & Co. Ed. 2. XVII + 442 pages, illus. 1936. 20/-net.

THE second edition of this excellent book, the first edition of which appeared in 1932, will be welcomed by all workers in soils and allied sciences. Those who valued the interesting scientific and philosophical presentation of the subject of pedology which characterized the first edition will not be disappointed in the present volume.

The material of the first edition is not only revised, corrected, and rearranged, but considerable new material is added, making a somewhat larger volume. The main changes have been made in the material dealing with Pedogenic Processes, the Clay Complex, Base Exchange, Soil Moisture, and Classification in which fields, particularly, notable advances have been made during the past three years.

The excellent bibliography of the first edition has been supplemented to the extent of 150 new references. The freshness, in fact almost uniqueness, of the approach to the whole subject of soil formation is a valuable feature and should appeal to all workers interested in soil relationships. (R. C. C.)

SCIENTIFIC PRINCIPLES OF WHEAT BREEDING

By N. I. Vavilov. Leningrad: Selkhozgiz. 246 pages, illus.

THIS book is written entirely in Russian by Dr. Vavilov well known to many American agronomists as Director of the U.S. S. R. Institute of Plant Industry in Leningrad. The first chapter contains detailed descriptions of the racial, species, and varietal potentialities of wheats. Three maps show the centers of origin of the 14-chromosome cultivated and wild eincorns and emmers; the geographical distribution of the botanical varieties of wheat having 42-chromosomes; and the centers of origin and distribution of the 28-chromosome wheats.

Discussions follow on hybridizing wheat with rye, Aeogilops, Hyanaldia, and Agropyrum; also on the crossing of wheats with different numbers of chromosomes. The author then discusses the breeding of wheat for yield, chemical composition, vegetative development, drouth resistance, frost resistance, immunity to diseases and insects, and response to fertilizers. A brief review is given of work on the breeding of wheat in 25 foreign countries as well as in the U. S. S. R., together with the pedigrees of the latest and most popular hybrids from all parts of the world.

Tables are presented showing the 18 best selections of spring wheat and the 16 best winter wheats recommended for various sections of the U. S. S. R. A careful appraisal of these varieties is made with regard to drouth resistance, maturity, productiveness, quality, stiffness of straw, resistance to disease, and other characteristics. A 20-

page bibliography of selected references on the genetics of wheat is a valuable feature of the book. (J. D. L.)

(N. B. We are indebted to Mr. J. W. Pincus, Consulting Agriculturist of 308 West 94th Street, New York City, for the information contained in this review. Copies of this book and translations may be obtained through Mr. Pincus.)

HUMUS

By Selman A. Waksman, Baltimore: Williams & Wilkins Co. XI + 494 pages, illus. 1936. $6.50.

THIS book should be of value to soil chemists and micro-biologists, as it deals with a subject which has seldom, if ever, before been treated in the form of a monograph. It not only contains a review of the literature (with over 1,300 references), but is a resumé of the work carried on by the author and some 25 associates at Rutgers University during a period of 15 years or more.

The author's attitude toward the chemistry of humus may well be illustrated by the following comments, which are typical of many that occur thruout the book: "No other phase of chemistry has been so much confused as that of humus, as a result of which it frequently becomes necessary to lay considerable emphasis upon the proper definition of the terms used.... It is as unreasonable to look upon humus as a simple chemical compound as it is to consider a plant or an animal as such an elementary system. Humus is extremely complex in composition."

The latter idea is emphasized particularly in the first of the three main sections of the book which deals with the history of our knowledge of humus. In this section the fallacious conceptions (which have sometimes persisted until surprisingly recently) of "humus" and "humic acid" as definite chemical entities are discussed and refuted.

The second section of the book deals with the "Origin and Nature of Humus." This is the largest of the three divisions of the book, comprising over half the text and containing nine of the 17 chapters. The first chapter on the "Origin of Humus" also discusses the probable chemical formulae of some of its known constituents (cellulose, lignin, etc.). The following chapter (Isolation of Definite Organic Chemical Compounds from Humus) takes up the methods of analysis originated by Schreiner and Shorey. Then, after a chapter on "Chemical Nature of Humus as a Whole," the author proceeds to give special attention to the biology of humus and the processes by which it is formed. Its formation is discussed in composts, in forest soils, in mineral soils, in peat, and in water systems.

The third section deals with the "Decomposition of Humus, Its Functions and Applications." Although the author thus finds it convenient in one section to treat humus in its state of formation and in another to regard it as a finished product, he realizes the difficulties involved in this distinction, and in introducing the first chapter of the third section comments as follows: "In view of the fact that most forms of humus.....are in a dynamic state, it is frequently difficult to differentiate between the formation and decomposition of

humus. The distinction is purely arbitrary, since both processes take place simultaneously."

He shows, however, that humus has characteristics sufficiently different from those of the organic matter from which it is derived so that the above-mentioned distinction can be recognized. Accordingly, the concluding chapters discuss its properties, its importance to agriculture, and particularly its relation to the science of pedology. Especially interesting in this last connection is the discussion in Chapter XVII of the distribution of humus in the various horizons of certain typical soil profiles.

An appendix gives a brief review of methods of analysis of humus and certain humic constituents. The bibliography which follows covers nearly 70 pages. (H. J. C.)

AGRONOMIC AFFAIRS

NEWS ITEMS

BULLETIN No. 603, entitled "The Adequacy of the Boron and Manganese Content of Natural Nitrate of Soda to Support Plant Growth in Sand Culture" by Dr. John W. Shive, has just been released by the New Jeresy Agricultural Experiment Station. Anticipating a widespread interest in it, the Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York City, by permission of the New Jersey Experiment Station, has reprinted this bulletin and will be glad to send copies, as long as the supply lasts, to all who desire them.

THE SECOND edition of the "Bibliography of References to the Literature on the Minor Elements and Their Relation to the Science of Plant Nutrition" by Professor L. G. Willis of the North Carolina Experiment Station is now in the course of preparation. It will contain approximately 700 additional references not found in the first edition. The inquiry for copies of the first edition far exceeded the supply. Accordingly, the Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York City, requests that they be notified promptly by all who desire to receive copies of the second edition.

THE SUMMER meeting of the Alfalfa Improvement Conference will be held at the University of Wisconsin, Madison, Wis., June 26 and 27. Those attending the meeting of the Corn Belt Section of the Society who wish to participate in the alfalfa conference may drive to Madison on Thursday, June 25, after the conclusion of the northern field trip from Urbana, Ill.

J. O. BEASLEY, Assistant Agronomist, Texas Agricultural Experiment Station, who has been making a special study of the microchemistry of the cotton seed, has resigned to take graduate work in genetics leading to the doctor's degree at Harvard University.

GLENN W. BURTON, formerly Instructor of Agronomy at New Jersey and who completed requirements for the Ph.D. degree at Rutgers University, has joined the staff of the U. S. Department of Agriculture as Associate Agronomist. His duties will involve improvement of southern grasses, with headquarters at Tifton, Georgia.

ARTHUR HAWKINS, who recently completed requirements for his M.S. degree at Rutgers University, has accepted a position at the University of Maine as Assistant Agronomist.

PROF. R. I. THROCKMORTON, head of the Department of Agronomy at Kansas State College, was tendered a dinner by 75 of his associates and friends on May 11 in recognition of "A quarter century of outstanding service to Great Plains agriculture and Kansas education". Former Secretary of Agriculture Dr. W. M. Jardine, who was head of the Department of Agronomy when Professor Throckmorton joined the staff in 1911, presided at the dinner. Professor Throckmorton was presented with a gold watch at the close of the program.

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YIELD AND COMPOSITION OF ALFALFA AS AFFECTED BY VARIOUS FERTILIZERS AND SOIL TYPES[1]

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THE mineral matter as well as the energy supplied by forage crops is of utmost importance in animal nutrition since various nutritional disorders have been traced directly to mineral deficiencies. Mineral deficiencies in forage crops may be corrected by supplementing the ration with the proper mineral compounds or perhaps indirectly by application of appropriate fertilizers to the soil. The latter should be preferable if the practice results in feed of better quality in addition to larger yields produced economically. The work here presented was undertaken with the object of determining the effect of various combinations of fertilizers upon yield and upon the mineral and nitrogen content of alfalfa grown on different soil types.

EXPERIMENTAL PROCEDURE

The experimental plats used occurred in series of five in fields which had been in alfalfa, *Medicago sativa*, for several years; and the fertilizer treatments applied annually were as follows:

Plat	Treatment	Lbs. per acre
Check	No fertilizer	
N	Nitrate of soda (15% N)	300
NP	Nitrate of soda	300
	Superphosphate (16% P_2O_5)	600
PK	Superphosphate	600
	Sultate of potash (50% K_2O)	200
NPK	Nitrate of soda	300
	Superphosphate	600
	Sulfate of potash	200

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[2]Professor of Soils and Research Assistant, respectively. The authors are indebted to H. B. Carroll, W. O. Passmore, I. M. Ingham, and E. C. Durdle, county agents, and B. L. Brown, H. S. Porter, H. Alexander, and S. D. Boyer, teachers of vocational agriculture, for their splendid cooperation in supervising the field work and in obtaining the yields and the crop samples for analysis.

The fertilizers were broadcast early in the spring, and the experiment represented five different soil types in seven fields in western Washington and five different soil types, three of which are unclassified, in five fields in eastern Washington.

The Cascade Range makes a natural division between the two widely divergent climatic conditions in eastern and western Washington. The high rainfall and moderate, equable temperature on the west side of the Cascade Range have been the cause of considerable leaching and of moderately rapid decomposition of organic matter during the process of soil formation, leaving the soil somewhat acid in reaction. The low rainfall and more extremely varying temperature on the east side of the Cascade Range have favored the formation of soils that have not been subjected to leaching and are neutral to alkaline in reaction, low in organic matter, and high in readily soluble mineral constituents, especially calcium.

The average annual precipitation over a period of 25 years at LaCenter, which is centrally located in the experimental area in western Washington, is 51.8 inches and that at Kennewick, which is representative of the experimental area in eastern Washington, is 6.8 inches. The average mean maximum and minimum temperatures for the same period at LaCenter are 77.6° F and 32.2° F, respectively, and at Kennewick, 92.6° F and 20.4° F, respectively.

The source of available moisture for plant growth on the plats in western Washington was that provided by occasional rains during the growing season and the supply stored in the soil from precipitation during the dormant season. The plats in eastern Washington were located in the irrigated region where the major part of the water for plant growth was provided by irrigation.

SAMPLING

Samples of plant material for analysis were obtained from representative areas 3 × 3 feet in each plat for both the first and second cuttings of alfalfa. First cuttings were obtained from 14 different series of plats and second cuttings from 10 different series. Of this total, 14 series were on fields which had received one application of fertilizers, eight on fields which had received two successive applications of fertilizers, and two on fields which had received three successive applications of fertilizers. All the samples for analysis were cut at the same stage of maturity, the half-bloom stage, which is generally preferred for cutting the alfalfa for hay. The plant material was shipped to the laboratory immediately after sampling, dried at 60° C, and weighed to determine the yields. The occasional weeds and grasses occurring in the alfalfa were separated from the dried samples which were then ground in a Wiley mill and stored in bottles until it was convenient to proceed with the analytical work.

CHEMICAL ANALYSIS

The official methods of the Association of Official Agricultural Chemists (1)[3] were used for the analyses of the ash, nitrogen, phosphorus, and calcium contents of the alfalfa samples; and the potassium content was determined by the Volk and Truog (14) cobaltinitrate method.

[3]Figures in parenthesis refer to "Literature Cited", p. 504.

EXPERIMENTAL RESULTS

EFFECT OF FERTILIZERS AND SOIL TYPE ON YIELD OF ALFALFA

Although yield data were obtained each cropping season following each fertilizer treatment, only those yields from which samples were taken for chemical analysis are reported in this paper. This procedure was considered desirable because the recorded yields are representative of the results in general and additional yield data, though occupying considerable space, would give very little additional pertinent information. The yields and composition reported for first and second cuttings of alfalfa hay on the various experimental plats are grouped separately for the western and eastern Washington areas in Tables 1 and 2, respectively. As might be expected, the data show a considerable variation in yield and composition of alfalfa and its response to fertilizers on different soil types. Some of the irregularities probably are due to plat variations. This factor was taken into consideration in the interpretation of the results as all the comparatively small variations occurring irregularly were ignored.

Inasmuch as the plats on any particular soil type were not duplicated in the same field and the yield data which are tabulated on the acre basis were calculated from actual yields of two representative 3 × 3 feet areas in each plat, small differences in yields may not be significant, but differences in total yields approximating or exceeding 1 ton of hay per acre probably are. It is noted that the crop yields in general were greater on the eastern than on the western Washington soils, the difference being especially pronounced in the yields of the second cuttings due probably to lack of moisture in the western Washington area.

With few exceptions, the application of any of the fertilizers caused an increase in the total yield. Regardless of the fact that alfalfa is a legume that is supposed to have the faculty of gathering its nitrogen from the air, the addition of a nitrogen fertilizer to a large percentage of the different soils, particularly those in western Washington, resulted in increased yields. The soil in all the fields was either well inoculated naturally, as in the arid part of the state, or artificially with effective strains of the proper nodule bacteria at the time of planting the alfalfa, as in the humid area, so that the young plants at least were well supplied with root nodules in all cases, and theoretically the crop should have been able to obtain all the nitrogen required for maximum growth. Apparently, the ideal condition with respect to fixed nitrogen was not attained in all soils, particularly in the soils of the humid area. In a former study (13), it was observed that the soils in western Washington, although moderately acid in reaction in general, can be inoculated with nodule bacteria without difficulty either with or without the addition of lime, and that the effect of several strains of the alfalfa nodule bacteria on the growth of the host plant does not vary greatly. It seems that the effect of the legume nodule bacteria on the host plant is controlled to a greater extent by the fertility conditions of these soils than by their reaction.

When the yields are averaged, as shown in Fig. 1, it appears that the effect of fertilizers differs in the two areas and also that the soils in

TABLE 1.—*Yield in tons per acre and composition of alfalfa hay grown on eastern Washington soils.*

Treatment	First cutting						Second cutting					
	Yield, tons	Per cent of dry matter					Yield, tons	Per cent of dry matter				
		Ash	N	P	K	Ca		Ash	N	P	K	Ca
Unclassified Loam, 1930*												
Check	1.69	8.89	1.91	0.204	1.51	1.96	1.51	8.05	2.29	0.227	1.72	1.67
N	2.09	8.65	2.26	0.257	1.97	1.78	1.74	9.00	2.66	0.275	1.87	1.73
NP	4.31	6.28	1.96	0.188	1.25	1.56	2.64	7.66	2.77	0.267	1.49	1.44
PK	4.25	7.41	1.83	0.214	1.90	1.26	1.73	8.14	2.79	0.293	1.91	1.35
NPK	4.25	8.59	2.13	0.259	2.61	1.42	2.39	8.38	2.70	0.291	2.29	1.39
Unclassified Sandy Loam, 1932†												
Check	3.87	7.92	1.86	0.230	2.00	1.14	2.41	9.40	2.20	0.205	2.04	1.81
N	3.49	7.71	2.03	0.213	1.88	1.30	2.41	9.01	2.26	0.218	1.88	2.05
NP	4.00	8.28	2.19	0.229	1.83	1.45	2.86	9.30	2.36	0.222	2.06	2.03
PK	3.74	7.35	2.01	0.241	1.94	1.13	2.69	10.47	2.43	0.244	2.23	2.35
NPK	3.41	9.79	2.41	0.262	2.29	1.61	2.73	10.38	2.48	0.241	2.63	1.32
Winchester Sand, 1929†												
Check	2.84	—	3.13	0.245	2.84	1.41	3.06	9.24	2.65	0.194	2.37	1.57
N	2.39	—	2.97	0.205	3.00	1.85	2.70	8.88	2.69	0.202	2.34	1.50
NP	2.80	—	3.00	0.245	2.83	1.54	3.50	8.71	2.78	0.236	2.25	1.50
PK	2.88	—	3.13	0.235	2.96	1.79	3.14	7.93	2.87	0.240	2.40	1.26
NPK	2.04	—	2.82	0.239	3.26	1.58	3.45	9.29	2.94	0.223	2.94	1.43
Winchester Sand, 1930*												
Check	0.98	11.90	2.95	0.211	2.03	2.09	1.02	10.67	3.08	0.224	2.54	1.79
N	0.73	10.37	2.65	0.189	1.79	2.21	1.16	9.91	3.15	0.218	2.78	1.60
NP	1.03	8.61	2.64	0.217	2.12	1.54	1.61	10.37	3.61	0.300	2.72	1.45
PK	1.30	8.09	2.68	0.232	2.15	1.39	1.61	9.12	3.08	0.247	2.73	1.50
NPK	1.14	10.07	2.72	0.228	2.40	1.75	1.19	10.57	3.40	0.294	3.46	1.42
Ritzville Sandy Loam, 1932*												
Check	1.56	11.15	3.59	0.373	2.46	2.42	0.93	8.70	2.79	0.277	2.43	1.46
N	1.49	10.55	3.34	0.323	2.28	2.25	1.18	9.17	3.23	0.266	2.89	1.32
NP	1.95	9.33	3.30	0.332	2.60	1.79	1.31	9.10	3.02	0.254	2.77	1.49
PK	1.67	9.68	2.83	0.270	2.29	1.83	1.04	9.33	3.16	0.273	2.72	1.68
NPK	2.69	8.91	3.21	0.317	2.25	1.62	0.88	8.01	3.10	0.259	2.04	1.59
Unclassified Gravelly Sandy Loam, 1930‡												
Check	1.51	10.27	2.06	0.241	2.20	2.44	—	—	—	—	—	—
N	2.16	10.44	2.15	0.258	2.29	2.34	—	—	—	—	—	—
NP	2.59	10.18	2.35	0.231	2.70	2.04	—	—	—	—	—	—
PK	4.10	11.15	2.44	0.237	2.77	2.59	—	—	—	—	—	—
NPK	3.45	9.34	2.27	0.207	2.19	1.99	—	—	—	—	—	—
Unclassified Loam, 1929†												
Check	1.79	8.46	1.81	0.198	1.54	1.58	—	—	—	—	—	—
N	2.38	9.30	2.15	0.235	1.76	1.66	—	—	—	—	—	—
NP	3.41	8.45	2.17	0.223	1.68	1.56	—	—	—	—	—	—
PK	3.15	8.19	2.16	0.201	2.05	1.27	—	—	—	—	—	—
NPK	3.67	7.67	2.20	0.231	2.20	1.25	—	—	—	—	—	—

*Following one year of fertilization.
†Following two years of fertilization.
‡Residual effect of fertilizers.

TABLE 2.—*Yield in tons per acre and composition of alfalfa hay grown on western Washington soils.*

Treatment	First cutting						Second cutting					
	Yield, tons	Per cent of dry matter					Yield, tons	Per cent of dry matter				
		Ash	N	P	K	Ca		Ash	N	P	K	Ca
				Puget Sandy Loam, 1932*								
Check	1.62	8.11	2.22	0.296	2.74	1.07	0.74	8.20	1.74	0.209	2.13	1.43
N	1.76	8.17	2.19	0.257	2.54	1.18	0.56	7.48	1.76	0.170	1.94	1.36
NP	2.19	8.41	2.70	0.293	3.10	0.96	0.89	7.58	2.60	0.217	1.94	1.25
PK	2.32	7.71	2.51	0.302	2.85	0.94	0.75	8.66	2.22	0.207	2.30	1.48
NPK	2.09	7.70	2.72	0.322	2.93	0.89	1.19	8.29	2.57	0.200	2.20	1.53
				Puget Silt Loam, 1930*								
Check	3.07	7.98	1.87	0.274	1.99	0.90	1.69	8.41	1.86	0.253	1.79	1.39
N	3.83	8.56	2.15	0.317	2.47	1.00	2.49	8.88	2.74	0.263	2.48	1.46
NP	4.31	8.01	1.63	0.263	2.26	0.62	2.52	8.56	2.19	0.240	1.72	1.16
PK	3.72	8.08	1.92	0.269	2.07	0.59	1.75	8.46	1.96	0.222	1.42	1.30
NPK	4.51	7.44	2.00	0.274	2.14	0.81	2.57	8.10	2.28	0.214	1.50	1.36
				Puget Silt Loam, 1932‡								
Check	1.32	9.14	2.24	0.278	1.73	2.03	0.84	8.87	2.29	0.243	1.61	2.36
N	3.22	8.55	2.54	0.274	2.39	1.41	1.44	7.96	2.52	0.259	2.39	1.54
NP	4.18	8.57	2.36	0.259	2.22	1.51	1.27	7.54	2.34	0.254	1.57	1.90
PK	2.46	9.42	2.62	0.328	2.39	1.64	0.77	9.62	2.40	0.265	1.57	2.50
NPK	2.75	9.10	2.77	0.284	2.31	1.54	1.93	7.23	2.57	0.282	1.36	1.70
				Felida Silt Loam, 1930*								
Check	0.43	10.87	1.85	0.426	2.41	1.73	1.44	10.13	2.38	0.429	2.79	1.28
N	0.94	8.27	1.84	0.314	2.32	1.46	1.45	12.75	2.39	0.340	2.34	1.43
NP	0.81	8.42	1.81	0.311	2.68	1.26	2.03	9.70	2.25	0.396	2.04	1.42
PK	0.68	9.19	1.98	0.446	2.75	1.48	1.20	9.67	2.35	0.385	2.89	1.36
NPK	1.45	8.50	1.54	0.342	2.58	1.23	1.86	9.20	2.32	0.318	2.45	1.36
				Lynden Sandy Loam, 1930*								
Check	0.39	15.27	2.96	0.259	0.87	2.98	—	—	—	—	—	—
N	0.35	11.57	2.78	0.229	0.55	3.15	—	—	—	—	—	—
NP	0.40	15.70	2.80	0.236	0.79	2.81	—	—	—	—	—	—
PK	0.35	15.83	3.27	0.314	1.55	2.51	—	—	—	—	—	—
NPK	0.48	16.12	3.01	0.288	1.55	2.33	—	—	—	—	—	—
				Dungeness Silt Loam, 1930†								
Check	2.14	8.68	2.10	0.235	1.96	1.51	—	—	—	—	—	—
N	2.14	9.78	2.20	0.237	3.49	1.20	—	—	—	—	—	—
NP	3.17	13.66	2.77	0.363	3.32	1.58	—	—	—	—	—	—
PK	3.43	9.40	2.53	0.331	2.80	1.45	—	—	—	—	—	—
NPK	3.22	10.07	2.28	0.324	2.88	1.27	—	—	—	—	—	—
				Felida Silt Loam, 1930*								
Check	0.68	9.42	1.81	0.391	2.73	1.37	—	—	—	—	—	—
N	1.53	8.88	1.91	0.344	2.57	1.21	—	—	—	—	—	—
NP	1.36	8.85	1.67	0.354	2.54	1.25	—	—	—	—	—	—
PK	0.77	9.23	1.87	0.367	2.09	1.54	—	—	—	—	—	—
NPK	0.94	9.30	1.75	0.378	2.63	1.35	—	—	—	—	—	—
				Lynden Sandy Loam, 1931†								
Check	—	—	—	—	—	—	0.08	9.00	1.79	0.390	2.73	1.32
N	—	—	—	—	—	—	0.12	7.48	1.21	0.235	2.29	1.28
NP	—	—	—	—	—	—	0.15	7.86	1.31	0.244	2.46	1.11
PK	—	—	—	—	—	—	0.18	7.80	2.23	0.219	2.71	1.03
NPK	—	—	—	—	—	—	0.18	8.29	1.70	0.221	2.37	1.38

*Following one year of fertilization.
†Following two years of fertilization.
‡Following three years of fertilization.

eastern Washington are better suited for alfalfa than the soils in western Washington irrespective of fertilizer treatments. The addition of nitrogen to the western Washington soils resulted in a relatively large increase in yield, whereas the same treatment for the eastern Washington soils affected the yield only slightly. When the nitrogen was eliminated from the fertilizers, as on the PK plats, the yield on the western Washington soils was increased less than from any other fertilizer treatment; whereas on the eastern Washington soils it was about the same as resulted from any of the other fertilizers.

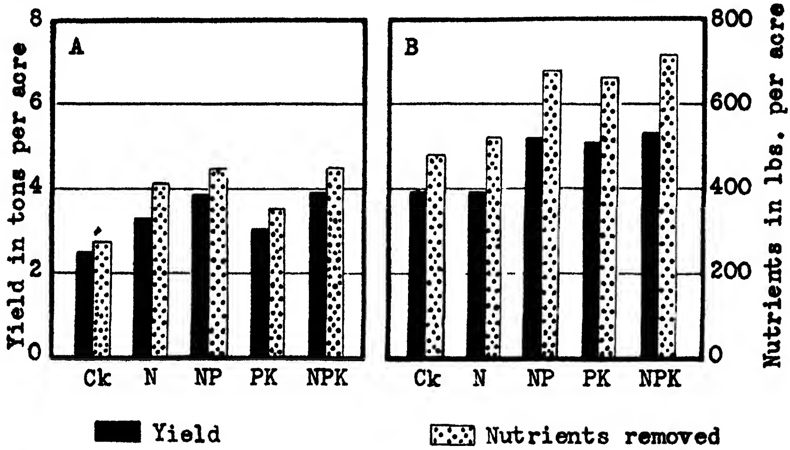

FIG. 1.—Average total yield and total amounts of nutrients (N, P, K, Ca) removed by alfalfa hay in western Washington (A) and eastern Washington (B).

A good crop of alfalfa can be expected to draw heavily on the mineral supply in the soil. An inspection of Fig. 1 shows that, on the average, the removal of nitrogen, potassium, calcium, and phosphorus combined is in proportion to the yield; and the quantities of each are in the descending order given, the last being taken up in relatively small amounts. Since the average nutrient content per ton of alfalfa hay on the basis of dry matter is greater in the eastern than in the western Washington samples, or 131 and 118 pounds, respectively, the loss of nutrients from the former soils by alfalfa is more significant.

The yield on different soil series and even on different soil types within the same series varied considerably, as is illustrated in Fig. 2 by several soil series and types from both localities. The total yield of two cuttings on the check plat of one of the Puget soils in western Washington was 2.36 tons and the average on the fertilized plats 2.93 tons; while on a different soil type in the same series, the yield on the check plat was 4.76 tons and on the fertilized plats 6.42 tons. In eastern Washington the yields of the two check plats on two unclassified soils, somewhat similar in texture but probably belonging to different soil series, were 3.20 and 6.28 tons, respectively; whereas the averages for the four fertilized plats of these soils were 5.32 and 6.30 tons, respectively.

Baker and Vandecaveye (2) have pointed out the effect of seasonal variations in climate, excluding soil moisture, on the yields of oats and vetch. Similar effects are indicated for alfalfa in Fig. 2. In 1930 the total yield of alfalfa on a Puget silt loam in western Washington was 4.76 tons per acre on the check plat and an average of 6.42 tons on the fertilized plats; whereas in 1932, even though the same fertil-

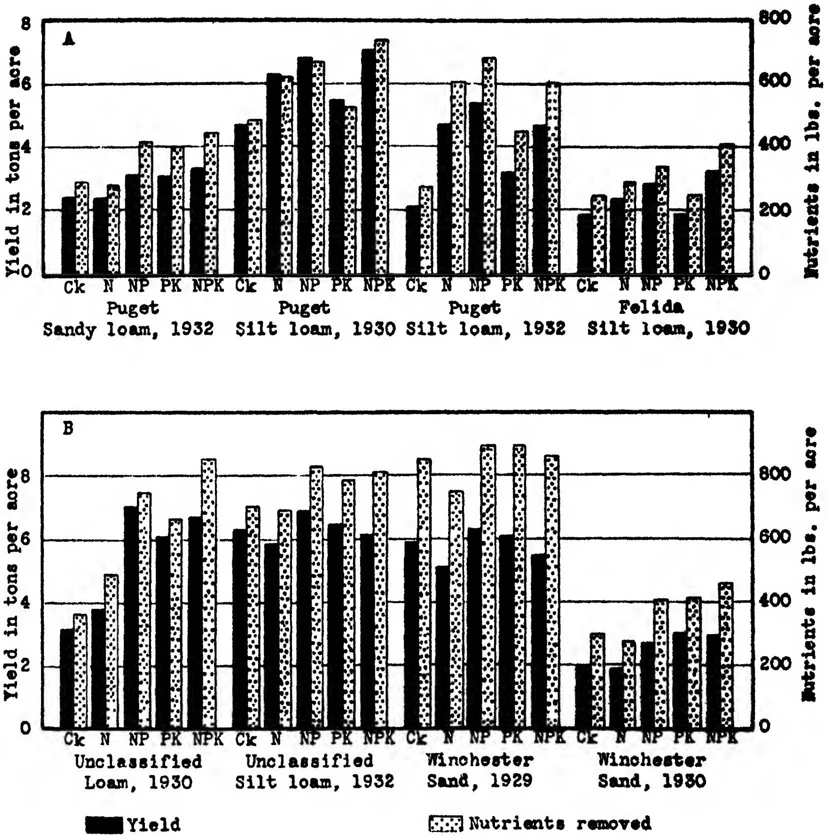

FIG. 2.—Effect of fertilizers on the total yields and on the amounts of nutrients (N, P, K, Ca) removed by alfalfa hay on different soil types in western Washington (A) and eastern Washington (B).

izer treatment had been repeated annually, but in this case the available moisture may not have been similar, the total yield from these same plats was 2.16 tons and 4.52 tons, respectively. On a Winchester sandy soil in eastern Washington the average yield per acre in 1929 was 5.90 tons on the check plat and 5.72 tons on the fertilized plats, and in 1930 with the same fertilizer treatment repeated and a similar amount of moisture available for the crop the yield was 2.00 tons and 2.58 tons, respectively.

Despite the effects of soil differences characterized by soil types and series, and the influence of local and seasonal variations in climate on the growth of alfalfa, a classification of the soils of western and eastern Washington in separate groups, as shown in Fig. 1, reveals interesting variations with respect to yields, amounts of nutrients removed, and response to fertilizer treatments. As already pointed out, the greater yields and the greater removal of plant nutrients occurred on the eastern Washington soils. The better response from nitrogen fertilizers was obtained from the western Washington soils, but the better response from phosphate and potash fertilizers with nitrogen omitted occurred in the eastern Washington soils. Owing to its greater yields and higher mineral content, alfalfa appears to be a desirable crop for the arid soils of eastern Washington with regard to both quantity and quality of feed. These two factors are precisely the ones that tax the fertility of the soil, and they may play a vastly more important rôle in affecting soil productivity and quality of production in the irrigated, eastern Washington area than in the humid areas of western Washington, if alfalfa is grown extensively for a long period of time on a large part of the farm.

EFFECT OF FERTILIZERS AND SOIL TYPE ON COMPOSITION OF ALFALFA

Although it is generally conceded that applications of the proper kind of fertilizers result in increased crop yields, the effect these fertilizers may have on the composition of the crop is still a controversial matter. The results of the determinations of the ash, nitrogen, phosphorus, potassium, and calcium content of representative samples of alfalfa of the first and second cuttings are reported in Tables 1 and 2. As may be noted, the effect of nitrogen, phosphorus, and potassium fertilizers on the composition of alfalfa differed in the same cutting when grown on various soil types, in the two cuttings from the same soil type, and in general in the two climatic areas represented.

Additions of nitrogen fertilizer to the soil in western Washington caused a decrease in percentage of nitrogen in alfalfa on the Lynden soils but little change on the Felida soils, whereas in eastern Washington it generally resulted in an increased percentage of nitrogen in alfalfa on the unclassified soils but no consistent variation in alfalfa on the Winchester and Ritzville soils. These variations apparently occurred regardless of varietal characteristics which could have been manifested as two different varieties of alfalfa, Grimm and common, were grown.

The application of phosphate fertilizers, although affecting the phosphorus content of alfalfa somewhat irregularly in both sections of the state, caused a marked increase in the percentage of phosphorus of the alfalfa hay on the majority of the soils in eastern Washington.

The response to potash fertilization was not manifested by any material increase in the potassium content of the alfalfa from the western Washington area except in that from one of the Lynden and

one of the Puget soils. The results of the eastern Washington area were a little more consistent as the application of potash fertilizers caused some increase in the percentage of potassium in the alfalfa hay of either the first or the second cutting on five of the seven soils used.

Certain general tendencies of the effect of nitrogen, phosphate, and potash fertilizers on the composition of alfalfa become apparent when the results of separate cuttings from each of the two groups of soils are averaged. This is graphically illustrated in Fig. 3. Taking the non-fertilized plats as a standard for comparison, it appears that the addition of nitrogen fertilizer generally caused some increase of the nitrogen content of the alfalfa hay from both the eastern and western Washington soils, but the increase was not always greater than that resulting from the PK treatments. Nitrogen alone applied to the western Washington soils had a strong tendency to cause a reduction of the phosphorus content of the alfalfa, but this tendency was counteracted though generally not completely overcome when phosphate fertilizers were used in combination with nitrogen. If the averages of the N plats are taken as a standard for comparison instead of the check plats, it is noted that the use of phosphate fertilizers caused an increase in percentage of phosphorus in the alfalfa hay in all except one case. The use of potash fertilizers resulted in no appreciable effect on the potassium content of alfalfa of either the first or second cuttings on the western Washington soils but had a definite tendency to increase the potassium content of both cuttings on the eastern Washington soils. The calcium content of the alfalfa was not affected materially by any of the fertilizer treatments but had a tendency to vary inversely with the yield as can be seen by comparing the average percentage of calcium indicated in Fig. 3 with the average yields shown in Fig. 1. The alfalfa on the check plats, which produced the lowest yields, contained the highest percentage of calcium, whereas the alfalfa from the NPK plats, which produced the highest yields, was lowest in calcium content. A study of the data in Tables 1 and 2 reveals that on an average the calcium and potassium contents of the alfalfa had a tenedncy to occur in inverse proportions. Similar observations were made by Fonder (5), Hoagland (7), and Sewell and Latshaw (12).

A comparison of the composition of the first and second cuttings of alfalfa on western Washington soils shows that the nitrogen, phosphorus, and potassium contents tend to be higher in the first than in the second cuttings. Precisely the opposite tendency is indicated for the two cuttings on the eastern Washington soils. Possibly one of the factors contributing to this difference is that the second cutting of alfalfa in the latter area was benefited by an increased nutrient content, resulting from a marked stimulation in biological activity which may be expected to occur in irrigated soils because of the ideal moisture conditions and considerable rise in soil temperature prevailing during that time of the season. In western Washington the soil temperature is not increased as much during this period and frequently the moisture supply in a large part of the root zone is limited so that biological activity is not at a maximum and the supply

of available nutrients for the second crop may not be very abundant. This is borne out by the data in Table 3, showing the composition of three successive cuttings of alfalfa on a Puget silt loam. The results indicate a decrease in phosphorus and potassium content for each successive cutting.

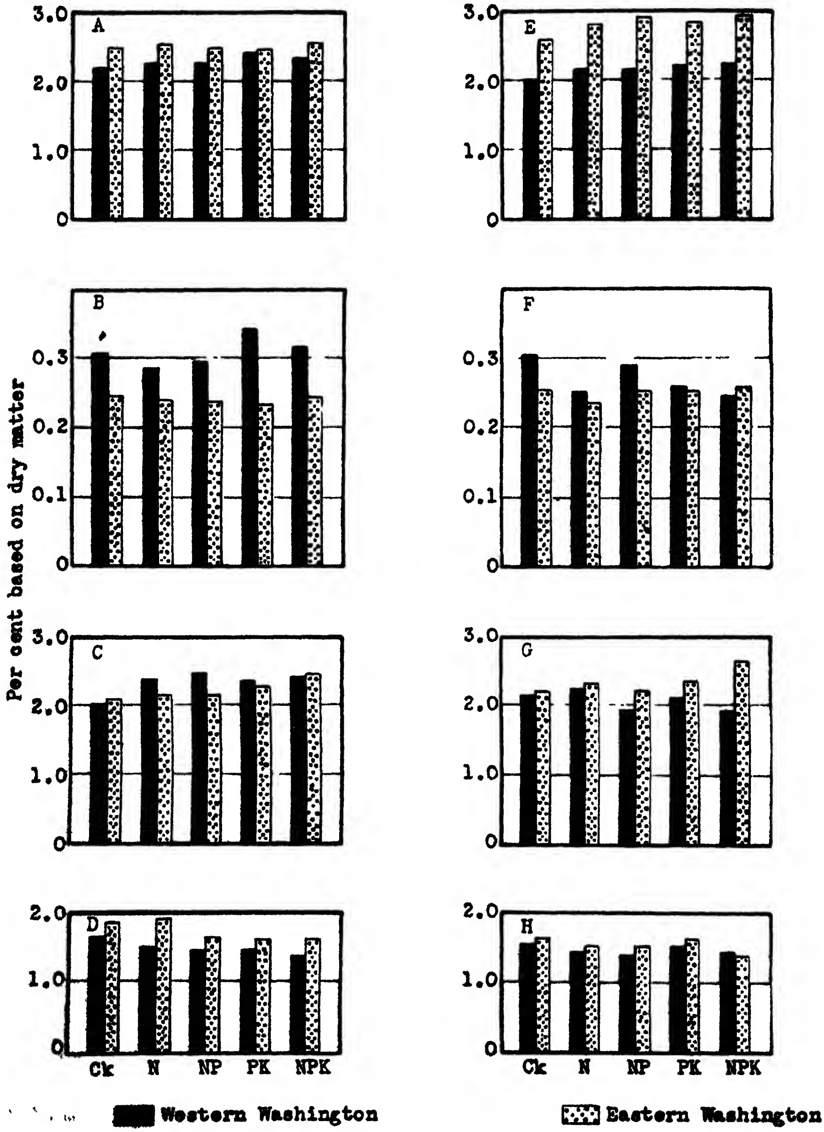

FIG. 3.—Effect of fertilizers on the average composition of the first and second cuttings of alfalfa grown on soils located in western and eastern Washington; A to D, first cutting; E to H, second cutting; A and E, nitrogen; B and F, phosphorus; C and G, potassium; D and H, calcium.

TABLE 3.—*Composition of three successive cuttings of alfalfa hay grown on a Puget silt loam soil of western Washington in 1930.*

Fertilizer treatment	Per cent of dry weight			
	N	P	K	Ca
	First Cutting			
Check	1.87	0.274	1.99	0.90
N	2.15	0.317	2.47	1.00
NP	1.63	0.263	2.26	0.62
PK	1.92	0.269	2.07	0.59
NPK	2.00	0.274	2.14	0.81
	Second Cutting			
Check	1.86	0.253	1.79	1.39
N	2.74	0.263	2.48	1.46
NP	2.19	0.240	1.72	1.16
PK	1.96	0.222	1.42	1.30
NPK	2.28	0.214	1.50	1.36
	Third Cutting			
Check	2.13	0.175	1.66	2.31
N	2.15	0.208	1.78	1.70
NP	2.22	0.189	1.63	2.07
PK	2.46	0.207	1.44	2.36
NPK	2.15	0.164	1.33	1.90

Conceivably, repeated annual applications of fertilizers for two or three years in succession might affect the composition to a greater extent than a single application. The results in this experiment indicate that on both the eastern and western Washington soils the second or third applications of fertilizer had no outstandingly greater beneficial effect upon the yield or composition of alfalfa than did the first year's application. A very favorable residual effect on yield following a single application of the fertilizers was observed, however, on one of the unclassified soils. The fertilizers were applied in 1929 and the yields of that year, as well as those of 1930 which are recorded in Table 1, were similar. As may be noted, the 1930 yields on all the fertilized plats on this soil were considerably greater than that on the check plat, but the composition of the alfalfa hay was not materially affected as a result of the previous fertilizer treatments.

EFFECT OF CLIMATE ON COMPOSITION OF ALFALFA

A study of the adjacent columns in Fig. 3 reveals that certain variations in composition of alfalfa which received identical fertilizer treatment in the two climatic areas seem to be traceable to climatic factors.

The average nitrogen content of both cuttings from the arid eastern section of the state was higher than that of the two cuttings from the humid western section. The difference amounts to 0.23% on the dry matter basis. If this is calculated in terms of actual nitrogen content, the difference is 9.8% in favor of the alfalfa from the eastern section.

Contrarywise, the alfalfa from the humid area contained a higher average percentage of phosphorus than that of the arid area even though it might be expected that the more acid soils of the former area would contain a smaller amount of available phosphorus and a larger amount of iron and aluminum to fix added phosphorus than the soils of the latter area. The difference amounts to 0.036% on the dry matter basis, or 15% in favor of the alfalfa hay from the humid area if calculated in terms of actual phosphorus content. This is in agreement with the results of Baker and Vandecaveye (2) for oats and vetch grown on the same soil types in the two localities, but at variance with the results of Ramsay and Griffiths (11) who reported a higher percentage of phosphorus in alfalfa grown in areas of lower rainfall than in alfalfa from areas of higher rainfall. The difference in rainfall in the three areas they studied was comparatively small, and its effect on the composition of alfalfa may have been outweighed by that of differences in soil characteristics. The generally high phosphorus content of alfalfa grown in western Washington probably is not due to soil characteristics but rather to a difference in the nutrition of the plant brought about by some climatic factors, such as humidity, soil temperature and moisture, light intensity, and possibly variations in daily and seasonal temperatures.

While the phosphorus content of alfalfa generally was higher in the samples from the humid western area, the calcium content in general was higher in the samples from the eastern arid area. Baker and Vandecaveye (2) obtained similar results with oats and vetch grown on identical soils in these two regions. Again the influence of climatic differences on the composition of the plant in the two regions seems to be manifested. In this case it is possible that a greater supply of soluble calcium in the eastern Washington soils, as well as climatological factors, may have favored the higher calcium content of the alfalfa in the latter area. The results of a large number of qualitative determinations show that generally the soils in western Washington contain much less readily soluble calcium than the soils in eastern Washington.

No pronounced influence of climate was expressed by the potassium content of the hay. The average percentage of potassium in the alfalfa grown in these two areas varied little except that potassium fertilization of the eastern Washington soils had a tendency to result in a greater potassium content of the alfalfa than the same treatment on the western Washington soils. Since the former soils in general contain a higher original supply of potassium and possibly also a greater amount in available form than the latter, there may here be a case of luxury consumption, such as was observed by Hoagland and Martin (8) and by Bartholomew and Janssen (3) for soils having an abundant supply of available potassium.

DISCUSSION

Alfalfa is produced extensively in the western half of the United States and its hay ranks high as a roughage for cattle feed. Many livestock feeders in the irrigated arid and semi-arid districts in the

West have used alfalfa hay successfully as the principal feed and at times as the exclusive feed for beef and dairy cattle without obvious development of nutritional disorders, such as have been reported by Eckles, *et al*, (4) in Minnesota and by Hart, *et al*, (6) in Wisconsin. These investigators found that, although dairy cows receiving a ration containing less than 0.43% calcium developed no symptoms of mineral deficiency, cattle fed on alfalfa grown on soils known to be low in available phosphorus suffered from serious nutritional disorders. Since the calcium content of the alfalfa hay grown on any of the soils comprised in the experiment discussed in this paper is well above 0.43% and since the average of all is over three times this amount, nutritional deficiencies are not likely to arise from this source.

The phosphorus content of the alfalfa produced on the phosphorus-deficient soils reported by Eckles, *et al*, (4) and by Hart, *et al*, (6) ranged from 0.143 to 0.189% on the basis of dry weight. The higher figure is less than those reported in Tables 1 and 2 with two exceptions and is about the same as that for hay produced in Germany, Australia, and Norway, which, according to Eckles and his coworkers, caused no nutritional troubles when fed to cattle. Although no minimum figure for phosphorus content that will preclude mineral deficiencies, is given by these investigators, it may be assumed that alfalfa hay containing 0.189% phosphorus should be relatively safe for general feeding purposes.

If the daily phosphorus requirements of dairy cows is 10 grams for maintenance and 0.5 to 0.7 gram per pound of milk produced, as estimated by Huffman, *et al*, (9), the maximum daily phosphorus requirements for cows producing 23.5 pounds of milk would be 26.45 grams. To supply this requirement in a ration containing 19 pounds of alfalfa hay, which Linsey and Beals (10) considered suitable for dairy cows, the phosphorus content of the hay would have to be 0.22%. This percentage is less than that obtained from the large majority of the samples recorded in Tables 1 and 2, showing that with rare exceptions the alfalfa hay represented by these samples should satisfy the high phosphorus requirements of lactating dairy cows.

Inasmuch as the phosphorus content of the alfalfa hay produced on both the western and eastern Washington soils reported in this paper is, with rare exceptions, adequate to meet the high requirements of dairy cattle, there is no general need for applications of phosphate fertilizers for the purpose of improving the quality of alfalfa and the only justification for their use is probable profitable returns in yield. In general, those soils which produced alfalfa hay with less than 0.22% phosphorus without the application of phosphate fertilizers were highly responsive to additions of these fertilizers not only in greater yields but also in a satisfactory increase in phosphorus content of the crop. Thus it seems hopeful that through the application of phosphate fertilizers to soils producing alfalfa low in phosphorus, it is possible to obtain a sufficient increase in yield to warrant the use of such fertilizers and at the same time improve the quality of the alfalfa by increasing its phosphorus content sufficiently to make it safe for all feeding purposes.

SUMMARY

The effect of various combinations of fertilizers upon the yield and upon the mineral and nitrogen content of alfalfa hay grown on various soil types was studied.

With few exceptions, the application of fertilizers caused an increased yield on both eastern and western Washington soils, but the average yield on the eastern Washington soils was greater than that on the western Washington soils irrespective of fertilizer treatments. Likewise, the amount of nutrients absorbed per ton of hay was greater on the former soils, but the amount of nutrients removed per acre was very much in proportion to the yield in both areas.

Nitrogen, phosphorus, and potassium fertilizers applied alone or in combination to the soils in western Washington had no appreciable effect on the percentage of those elements in the alfalfa hay in the majority of cases, but when applied to eastern Washington soils the phosphorus and potassium contents of the hay had a tendency to increase as a result of phosphate and potash fertilization. The calcium content of the alfalfa did not seem to be affected appreciably by the application of fertilizers, but had a tendency to vary inversely with the yield. On an average the higher percentages of nitrogen and calcium were found in the alfalfa from the eastern Washington soils and the higher percentages of phosphorus in the alfalfa from the western Washington soils.

Climatic conditions exclusive of available water appeared to influence the composition of alfalfa in the two areas of the state and on the same experimental plat in successive years. Alfalfa grown in the humid area of western Washington generally contained a higher percentage of phosphorus than that grown in the arid area of eastern Washington. Also, the composition of the alfalfa in successive years on the same soil varied in either area.

In the great majority of cases the alfalfa hay contained adequate amounts of the principal mineral elements, phosphorus and calcium, for general feeding purposes of livestock and for the high requirements of lactating dairy cows. In the few exceptional cases in which the phosphorus content of the alfalfa hay was below a certain assumed minimum, it was increased sufficiently by phosphorus fertilization to raise it above that minimum and at the same time result in appreciable increases in yield.

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STUDIES ON GROWTH IN RICE[1]

C. Roy Adair[2]

STUDIES on the growth curve of rice have been reported for the more important rice-producing countries of the world. There is, however, little or no data available on this subject in the United States. Information on the growth of rice under field conditions should be of interest to those concerned with the improvement and production of rice in this country. Therefore, a study of the growth of three varieties of rice was conducted at the Rice Branch Experiment Station, Stuttgart, Ark., during the 3-year period 1932–34. Increases in height, in dry weight, and in the number of tillers and leaves per plant were recorded each year, and the results obtained are reported herein.

MATERIAL AND METHODS

The varieties used were Caloro, a midseason short-grain variety; Early Blue Rose, an early-maturing medium-grain variety; and Edith, an early-maturing long-grain variety. These varieties were described by the writer (1)[3] in 1934.

The rice was sown on May 14 in 1932 and 1934 and on May 10 in 1933 on a well-prepared seedbed. The plants were spaced about 4 inches apart in rows 1 foot apart.

Since the plants were grown under ordinary field conditions, they were subject to varying temperatures, soil conditions, and attacks by insects and diseases.

Each year the rice was irrigated about 3 or 4 weeks after seeding, and the water was held for about 4 weeks. The land was then drained and allowed to dry and again submerged, the water being held throughout the remainder of the growing season. The depth of the water during the submergence period was 3 to 6 inches. This method was followed because it is recommended by Isely and Schwardt (4) for the control of root maggots, the larval stage of the rice water weevil (*Lissorhoptrus simplex* Say). The periods from seeding to first irrigation, to drainage, and to resubmergence were 22, 47, and 60 days, respectively, in 1932; 31, 62, and 72 days in 1933; and 30, 56, and 67 days in 1934.

The weather for the 3 years was somewhat variable. The monthly rainfall for the 5 months period of May to September in 1932 ranged from 1.11 inches in August to 4.39 inches in July, and the total was 13.98 inches; in 1933 the rainfall ranged from 1.08 inches in June to 9.97 inches in May, and the total was 28.00 inches; and in 1934 the rainfall ranged from 1.25 inches in August to 6.56 inches in June, and the total was 17.52 inches.

The daily maximum and the average monthly daily maximum, minimum, and mean temperatures for the period May 10 to September 30 in 1932, 1933, and 1934 are shown in Fig. 1.

The temperatures were rather uniform during the entire growing season of 1933, whereas they were very high in July and August of 1932 and 1934 and rather variable and much lower in September.

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Arkansas Agricultural Experiment Station. Received for publication February 7, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 514.

Each year the first 10-plant samples were taken about 2 weeks after seeding, at which time there was only one tiller per plant. Thereafter a 10-plant sample of each variety was taken each week during the growing season. The studies were confined to portions of the plant above the root system. Green weights were not

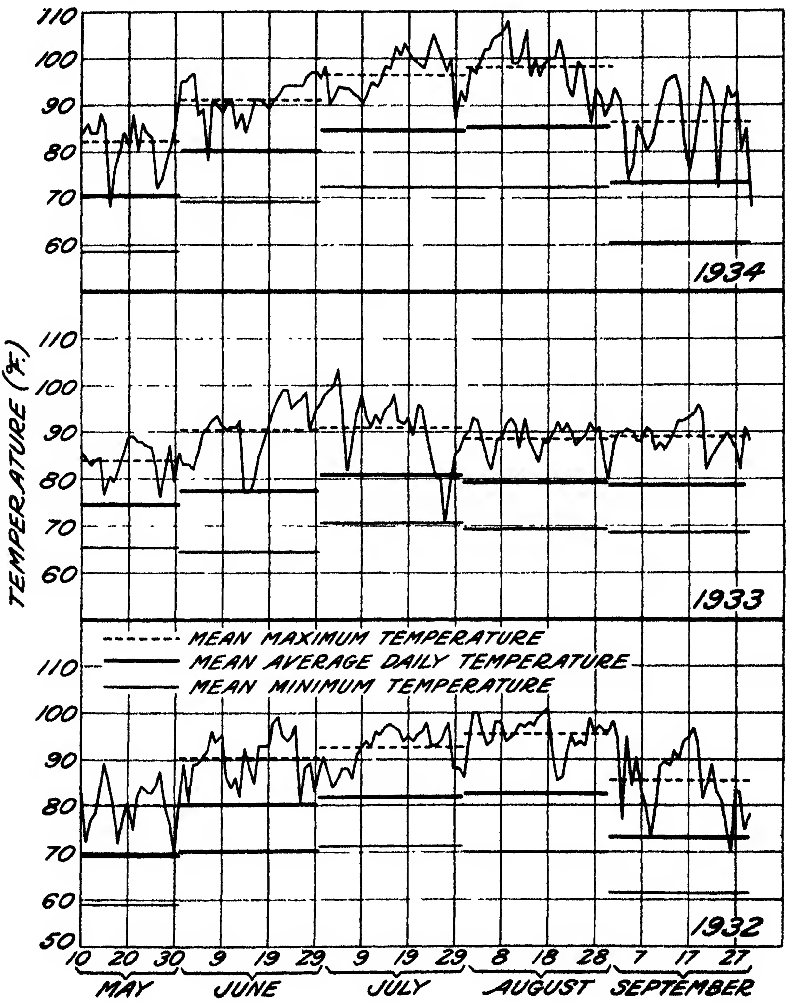

FIG. 1.—Daily maximum and average monthly daily maximum, minimum, and mean temperatures for the period from May 10 to September 30 in 1932, 1933, and 1934.

recorded because the plants had varying amounts of water adhering to them, which make such weights unreliable. To reduce the error introduced by measuring a different set of 10 plants each week as much as possible, abnormally small plants were not taken.

The number of tillers, leaves, and panicles and the height to tip of distal leaf and to tip of panicle for each individual plant and the oven-dry weight of the 10 plants were recorded. The averages per plant of each factor studied were then computed.

RESULTS

NUMBER OF TILLERS, LEAVES, AND PANICLES

The word "leaf," as used in this paper, refers to a leaf that has both a sheath and a blade. The first two leaves do not have blades, therefore a plant recorded as having two leaves would actually be in the fourth leaf stage.

Each year some of the plants of each variety started to tiller 3 weeks after seeding and the increase in number of tillers per plant was very rapid until the end of the sixth week. There was some tillering after that time, but late tillers usually did not bear panciles. The number of tillers per plant was higher about the middle of the growing season than was the number of panicles per plant at maturity. All tillers that formed panicles started growth within a period of about 3 weeks. This agrees with the results reported by Ramiah (7) and Watanabe (11). There were many more tillers in 1933 that did not bear panicles than in 1932 and 1934.

In the 3-year period 1932–34, during the seedling and tillering stages of growth, including the first 6 weeks after emergence, the average number of tillers per plant and leaves per culm was for Caloro 3.6 and 3.4, for Early Blue Rose 3.1 and 3.3, and for Edith 3.5 and 3.3, respectively.

In the jointing and booting stages of growth, covering the second 6 weeks after emergence, the average number of tillers per plant and leaves per culm was for Caloro 7.9 and 4.7, for Early Blue Rose 6.9 and 4.8, and for Edith 7.4 and 4.4, respectively.

During the heading and maturing stages of growth, covering the third 6 weeks after emergence, the average number of tillers per plant and leaves per culm was for Caloro 6.1 and 4.2, for Early Blue Rose 6.2 and 4.5, and for Edith 6.2 and 4.0, respectively. The average number of panicles per plant during the heading and maturing stages of growth was for Caloro and Early Blue Rose 5.4 and for Edith 5.6, respectively.

The number of leaves per culm increased until panicles were formed and then remained constant or decreased as the older leaves died and were broken off. There was no marked difference for the three varieties in the number of leaves produced per culm. The number was slightly lower for all varieties in 1932 than in 1933 and 1934, and the highest number was produced in 1933.

GROWTH IN HEIGHT

The average increase in height of plant for the three varieties is shown in Fig. 2. The crown roots were well established in about 4 weeks after seeding. Then followed a period of rapid growth in height. This second period of growth corresponds to that reported by Pope (6) in barley. The first irrigation water was applied each year at

about the time the crown roots were well established, and undoubtedly the presence of standing water favored rapid growth in height.

According to Isely and Schwardt (4), root maggots begin to do serious damage to the roots about 3 weeks after the first irrigation water is applied. Root-maggot injury was probably the cause of the inflection of the height-growth curves that occurred in most cases about 6 or 7 weeks after seeding. The average growth curves (Fig. 2)

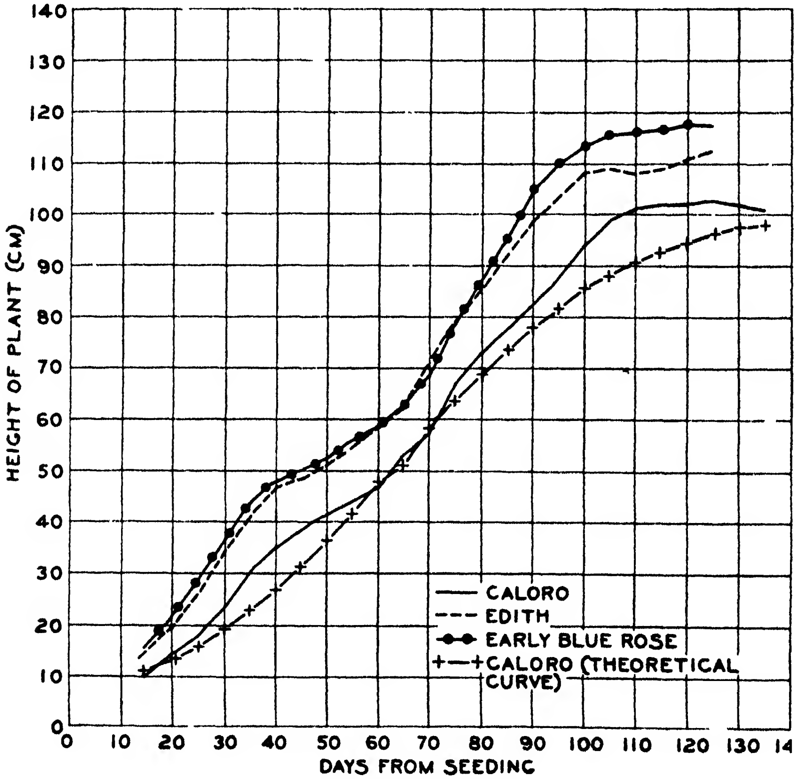

Fig. 2.—Average increase in plant height for the 3-year period 1932 to 1934, inclusive.

show a relatively rapid increase in height for about 6 weeks after seeding then a slower rate of increase for about 2 weeks, followed by a rapid increase until flowering time, after which there was but little increase.

Somewhat similar results are reported by Ramiah (7) and Watanabe (11). However, Watanabe did not find a period of slow growth at about 6 or 7 weeks after seeding. The height to tip of panicle and to tip of the most distal leaf reached its maximum at the same time. Copeland (2, page 10), working with Caloro, reports similar results. The height to tip of panicle was greater than that to tip of distal leaf for Caloro and Early Blue Rose but less for Edith. The reverse, how-

ever, was true for Early Blue Rose in 1934. During the time the land was drained there was very little increase in plant height, but, the root area probably increased, and when the land was resubmerged during the jointing stage the increase in height of the plants was very rapid. In 1932 and 1933 the increase in height was rather uniform for all varieties until flowering time, when the curves were inflected. This agrees with the report of Van de Sande-Bakhuyzen and Alsberg(10) for wheat but differs from that of Pope (6) for barley.

In 1934 the second period of rapid growth in height started about the same time as in 1932 and 1933, but about 80 or 85 days after seeding the curve of each variety was inflected. Early Blue Rose and Edith increased in height very little after that time. The temperatures, as shown in Fig. 1, were very high about the middle of July 1934 and much lower during the latter part of July and the first part of August. Temperatures were again high about the middle of August and lower later in August when Edith and Early Blue Rose flowered and set seed. These fluctuations in temperature occurred at the time growth in height ceased. The weather was again warm about the time Caloro showed an increase in height. There were similar temperature fluctuations in 1932 and 1933, but not so extreme as in 1934. The changes in temperature in 1934 probably were a contributing factor in the cessation of growth in height.

The 3-year average height curve for Caloro (Fig. 2) shows a period of relatively slow growth for about 60 days, followed by a period of rapid growth until about 110 days after seeding. The curve was then inflected, and there was very little increase in height thereafter. The average height curves for Early Blue Rose and Edith also show a period of relatively slow growth for about 60 days, followed by a period of rapid increase in height. The curves were inflected about 100 days after seeding, although there was a slight increase in height during the next 20 days.

GROWTH IN WEIGHT

The average weight-growth curves for the three varieties are shown in Fig. 3.

The average increase in plant weight (Fig. 3) was slow for the first 5 weeks after seeding, then followed a period of rapid increase which coincided with the rapid development of the tillers owing to the activity of the tiller roots. A slight inflection of the weight curves usually occurred a little later than the inflection in the height curves. The rate of increase in weight was very rapid during the jointing stage. In 1932 and 1933 there was an inflection of the weight curves about 10 days after flowering. Somewhat similar results are reported by Ueda (9) and Watanabe (11). In 1934 the weight curves were inflected about the time the panicles emerged from the sheaths. This probably was due to abnormal temperatures which caused poor development of the grain. The weight of culms was slightly lower and the weight of panicles was much lower in 1934 than in 1933. In 1932 and 1933 there was an increase in plant weight for each variety on the last day.

As the plants reached maturity the leaves at the base died and

many were broken off; there also was probably some loss due to leaching. During the last few days of the growth period late tillers grew from the crown of the plants. In most cases this caused the total weight of the plant to be high when the last samples were taken.

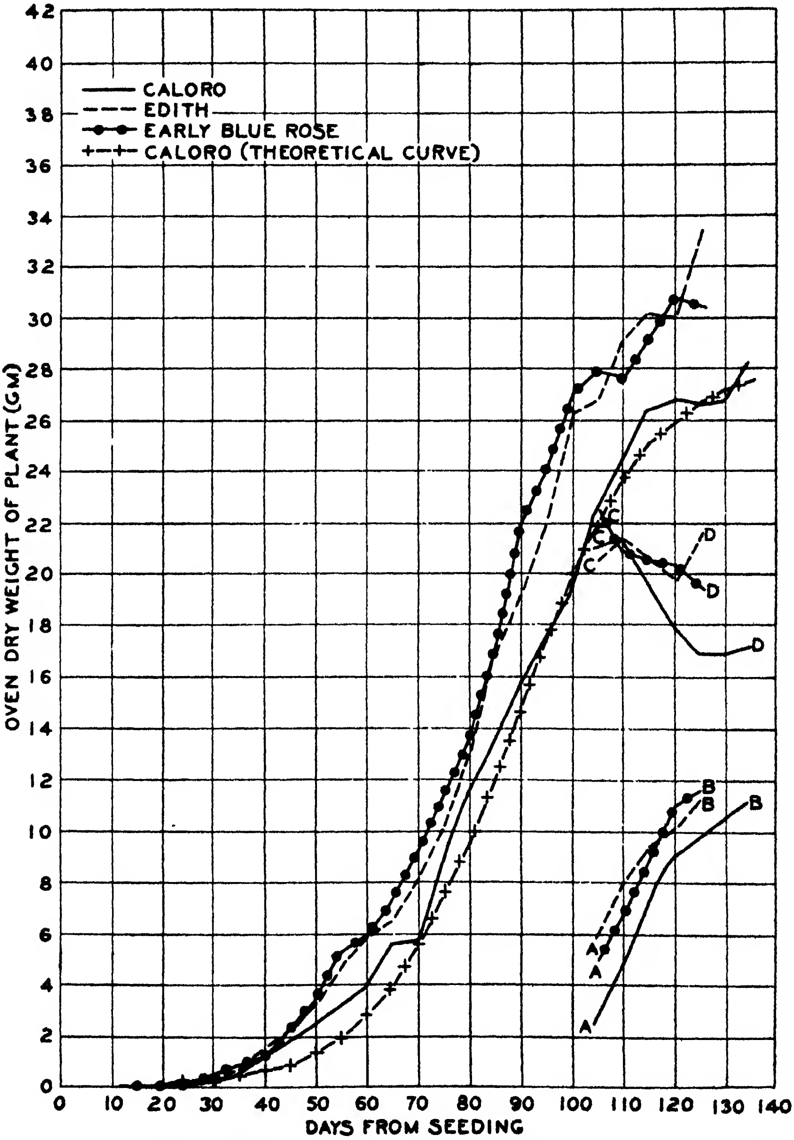

FIG. 3.—Average increase in plant weight for the 3-year period 1932 to 1934, inclusive, and the average weight of panicles (A-B) and of culms (C-D) per plant.

After the grain started to form, the weights of culms and panicles were determined separately. The weight-growth curves of the entire plants show some increase until maturity. However, there was a slight decrease in the weight of the culms soon after flowering, and the increase in weight after that time was due to the development of the grain.

GROWTH EQUATIONS APPLIED TO THE DATA

The equation for an autocatalytic monomolecular reaction, as given by Robertson (8), was applied to the data to compute the theoretical curves of growth in height and weight. This equation is expressed by the formula Log. $\frac{X}{A-X} = K\,(t - t_1)$, in which X equals the magnitude of growth at time t, A is the maximum growth attained, t_1 is the time at which X equals $\frac{1}{2}A$, and K is a constant the size of which determines the slope of the curve. The theoretical curves obtained for height and weight of Caloro are shown in Figs. 2 and 3, and the values of A, K, and t_1 are given for the height- and weight-growth curves for each variety in Table 1.

TABLE 1.—*Values of A, K, and t_1 in the formula Log. $\frac{X}{A-X} = K\,(t-t_1)$ for height to tip of distal leaf and oven-dry weight per plant of the Caloro, Early Blue Rose, and Edith rice varieties measured and weighed at progressive stages of development.*

Variety	Year	Height			Weight		
		A, cm	K	t_1	A, grams	K	t_1
Caloro	1932	94.82	0.0165	68.85	14.639	0.0275	97.88
	1933	116.08	0.0212	62.82	39.670	0.0345	86.98
	1934	98.74	0.0190	60.82	30.799	0.0373	82.01
Early Blue Rose	1932	110.36	0.0200	60.63	25.642	0.0320	88.44
	1933	128.78	0.0202	65.21	40.699	0.0372	85.54
	1934	115.63	0.0204	61.37	28.244	0.0373	77.12
Edith	1932	106.12	0.0168	57.37	30.153	0.0371	94.60
	1933	130.24	0.0168	62.98	46.324	0.0291	83.27
	1934	106.62	0.0179	50.10	34.709	0.0303	87.75

Robertson (8), working with oats and sunflowers, and Gaines and Nevens (3), working with sunflowers and corn, found that the theoretical curve conforms rather closely to the actual curve and place a great deal of significance on the values of the constants in this equation. On the other hand, Klages (5), working with winter and spring wheats, oats, barley, and flax, concludes that no significance can be attached to the values of these constants.

Ueda (9), in studies with the Aikoku rice variety, used this equation to reproduce the dry-weight-growth curve. He studied transplanted seedlings, however, and weights were not taken until they were 7 weeks old. His results, therefore, are not entirely comparable with those of the writer. The computed dry-weight-growth curve in Ueda's

studies lagged behind the actual curve in the early growth stages, whereas in the writer's study the 3-year average theoretical curve for Caloro lagged behind the actual curve in the early, middle, and late stages of growth (Fig. 3). The 3-year average theoretical height curve for Caloro lagged behind the actual curve in both the early and late stages of growth (Fig. 2).

The inflection of the growth curves, assumed to be caused by root maggot injury and adverse weather conditions, probably accounts for the coincidence of the theoretical and the actual growth curves in the writer's studies.

Gaines and Nevens (3) also attach considerable significance to the values of A/K and K/A. They define K/A as "a specific constant representing inherent growth velocity" and A/K as "a specific constant representing inherent final growth capacity." K/A varies in an inverse ratio to crop yield, and A/K varies directly with crop yield.

The values of A/K and K/A for height- and weight-growth were determined. The values of A/K and K/A for height growth within varieties did not conform to the definition, except the values of K/A for Early Blue Rose. The values of A/K and K/A for weight growth conformed to the definition within Caloro and Edith but not Early Blue Rose. A comparison of the values of these constants for increases in height and weight showed inconsistenices among the three varieties.

SUMMARY

The plants began to tiller about 3 weeks after seeding, and by the end of the sixth week all tillers that were to form panicles had started growth. The number of leaves per culm increased slowly until panicles were formed and then remained constant.

Increase in plant height was relatively rapid the first 6 weeks after seeding, then it was slow for about 2 weeks, followed by a rapid increase until flowering time, after which there was little increase. The 2 weeks of slow growth were probably due to root injury by maggots.

The increase in plant weight was slow for the first 5 weeks, after which tillers became established and, for a short time, owing to the activity of tiller roots, the weight increased rapidly. The rate of increase was then somewhat slower for about 2 weeks, after which, during the jointing stage, there was a rapid increase in weight. The weight of the panicles increased until maturity, but that of the culms, after flowering, decreased slightly.

There was an early inflection of the height and weight curves in 1934. This was attributed to adverse weather conditions.

Each variety attained a greater height and weight of plant in 1933 than in 1932 and 1934.

In these studies little significance could be attached to the values of A/K and K/A from the growth equation Log: $\frac{X}{A - X} = K\ (t - t_1)$.

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INFLUENCE OF FERTILIZATION, IRRIGATION, AND STAGE AND HEIGHT OF CUTTING ON YIELD AND COMPOSITION OF KENTUCKY BLUEGRASS (*POA PRATENSIS* L.)[1]

G. B. MORTIMER AND H. L. AHLGREN[2]

OUR knowledge relative to the influence of fertilization and height of cutting on the yield and composition of Kentucky bluegrass is not as complete as would be desired. Because of this fact an experiment to cover these phases in part was begun in 1928 on the East Hill University farm at Madison, Wis., on an area which had for at least 30 years previously been in bluegrass sod. Results for a 7-year period, 1928 to 1934 are presented. The studies were made on a Miami silt loam type of soil sloping gradually to the north and were confined to (a) yields as influenced by various fertilizer, cutting, and irrigation treatments; (b) the effect of various fertilizer treatments on the chemical composition of the grass from the standpoint of its nutritive value; and (c) the seasonal recovery of nitrogen.

GENERAL PLAN OF THE EXPERIMENT

The data reported represent the results obtained from 10 1/160 acre plats each separated by a 2-foot alley and numbered consecutively from 1 to 10.[3] The fertilizer and irrigation treatments for each of the plats during the 7-year period are given in Table 1. The fertilizer and cutting treatments for each of the 10 areas are given along with other data in the tables of yields. Plats 1, 2, 3, and 4 have been subjected to the same cutting and fertilizer treatment since 1928, the grass having been removed regularly when 4 to 5 inches high at 1½ inch levels. In the case of plat 5 the grass was cut when 4 to 5 inches high to ground level, which is an approximation of close grazing, although it differs in that a recovery period is always given. The treatment of plat 6 is similar to that of plat 5 except that the grass was not removed until it attained a height of 8 to 10 inches. On plats 7 and 8 an attempt was made to study the effect of complete fertilization, including nitrogen, as compared with mineral fertilization without nitrogen, while on plats 9 and 10 the efficiency of nitrogen used alone as against complete fertilization was measured. On all of these plats, namely, 7, 8, 9 and 10, the grass was cut regularly when it reached a height of 4 to 5 inches leaving a stubble of 1½ inches.

[1]Contribution from the Department of Agronomy (Paper No. 110), Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director of the Station. Received for publication March 28, 1936.

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[3]The 10 plats referred to above were selected from a group of approximately 80 on which various fertilizer and cutting studies were conducted by Professor Mortimer. The results and conclusions presented for these 10 areas are typical and representative of those which would have obtained for all plats if they had been included in this report. Moreover, the results for each plat may be considered replicated from year to year during the 7-year period these trials were in progress. The general trend from year to year on the same plat and the significant differences as between various plats appears to be ample justification for this assumption.

Year	Treatment of Plat 1	Treatment of Plat 2	Treatment of Plat 3	Treatment of Plat 4	Treatment of Plat 5
1928	100 lbs. 16% $NaNO_3$	100 lbs. $NaNO_3$; 300 lbs. 20% S. P.; 150 lbs. KCl; 1 T. ground limestone	200 lbs. Calurea	100 lbs. $(NH_4)_2SO_4$	
1929	375 lbs. 16% $NaNO_3$	375 lbs. $NaNO_3$; 300 lbs. 20% S. P.	180 lbs. Calurea	300 lbs. $(NH_4)_2SO_4$	
1930	500 lbs. 16% $NaNO_3$	500 lbs. $NaNO_3$	240 lbs. Calurea	400 lbs. $(NH_4)_2SO_4$	
1931	750 lbs. 16% $NaNO_3$ (irrigated)	750 lbs. $NaNO_3$ (irrigated)	353 lbs. Calurea (irrigated)	600 lbs. $(NH_4)_2SO_4$	500 lbs. 20% S.P.; 200 lbs. KCl; 400 lbs. $(NH_4)_2SO_4$ (irrigated)
1932	875 lbs. $NaNO_3$ (irrigated)	875 lbs. $NaNO_3$ (irrigated)	412 lbs. Calurea (irrigated)	700 lbs. $(NH_4)_2SO_4$ (irrigated)	400 lbs. $(NH_4)_2SO_4$ (irrigated)
1933	1,000 lbs. $(NH_4)_2SO_4$; 500 lbs. 20% S. P.; 200 lbs. KCl; 1,000 lbs. limate (irrigated)	1,250 lbs. $NaNO_3$ (irrigated)	1,000 lbs. $(NH_4)_2SO_4$ (irrigated)	1.000 lbs. $(NH_4)_2SO_4$, 500 lbs. 20% S. P.: 200 lbs. KCl; 1,000 lbs. limate (irrigated)	1,000 lbs. $(NH_4)_2SO_4$ (irrigated)
1934	1,160 bs. $(NH_4)_2SO_4$ (irrigated)	1,160 lbs. $(NH_4)_2SO_4$ (irrigated)	1,160 lbs. $(NH_4)_2SO_4$ (irrigated)	1,160 lbs. $(NH_4)_2SO_4$ (irrigated)	1,160 lbs. $(NH_4)_2SO_4$ (irrigated)

Year	Treatment of Plat 6	Treatment of Plat 7	Treatment of Plat 8	Treatment of Plat 9	Treatment of Plat 10
1928		300 lbs. 20% S. P.; 150 lbs. KCl; 1 ton limestone	300 lbs. S. P.; 150 lbs. KCl; 1 ton limestone		
1929		300 lbs. 20% S. P.	300 lbs. 20% S. P.		
1930					
1931	500 lbs. 20% S. P.; 200 lbs. KCl; 400 lbs. $(NH_4)_2SO_4$ (irrigated)				
1932	400 lbs. $(NH_4)_2SO_4$ (irrigated)	400 lbs. $(NH_4)_2SO_4$ (irrigated)	(irrigated)	200 lbs. $(NH_4)_2SO_4$ (irrigated)	500 lbs. 20% S. P.; 200 lbs. KCl; 250 lbs. $(NH_4)_2SO_4$ (irrigated)
1933	1,000 lbs. $(NH_4)_2SO_4$ (irrigated)	400 lbs. $(NH_4)_2SO_4$ (irrigated)	(irrigated)	400 lbs. $(NH_4)_2SO_4$ (irrigated)	400 lbs. $(NH_4)_2SO_4$ (irrigated)
1934	1,160 lbs. $(NH_4)_2SO_4$ (irrigated)	750 lbs. 20% S. P.; 200 lbs. KCl; 1,000 lbs. $(NH_4)_2SO_4$ (irrigated)	750 lbs. 20% S. P.; 200 lbs. KCl (irrigated)	680 lbs. $(NH_4)_2SO_4$ (irrigated)	500 lbs. 20% S. P.; 680 lbs. $(NH_4)_2SO_4$ (irrigated)

The cutting was done with a lawn mower equipped with a grass catcher and samples of this grass (approximately 2 pounds green weight) were taken for chemical analysis. The samples thus obtained were placed in paper bags and stored at room temperature until early winter, when they were oven dried at 90° C, ground to pass an 80-mesh sieve, and analyzed. The methods used for all analyses are those given in the third edition of the Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists. Samples for moisture determination for each plat were collected at the time of cutting, placed in air-tight containers, and dried in an oven for 48 hours at 90° C.

The mineral fertilizers were always applied in the spring (April) at such times during the course of the experiment as soil tests revealed the need. The amounts used per plat during the 7-year period appear in the tables. At the outset a single application of nitrogen was made in the spring, but as the experiment progressed it became increasingly apparent that the effect did not last through the growing season. In 1934 applications were made at the completion of each cutting. The amount used has varied from year to year, but generally it has been increased in an attempt to determine the maximum quantity of nitrogen that can be utilized by the plant. The form of nitrogen was not considered significant in the light of previous investigations not herein reported. Due to extreme drouth conditions prevailing, a system of irrigation was initiated in 1931 and continued through 1934. Water was applied to all 10 plats with a hose in sufficient quantities throughout the growing season to maintain the soil in a reasonably moist condition.

RESULTS

EFFECT OF VARIOUS FERTILITY AND CUTTING TREATMENTS ON YIELD

Tables 2 to 21, inclusive, provide the information in detail with respect to yield studies as influenced by various fertility, irrigation, and cutting treatments, covering a period of 7 years, 1928 to 1934. It is clear from a review of the data that nitrogen and water were the two most important factors limiting the production of grass.

TABLE 2.—*Yields per acre of plat 1 variously fertilized and irrigated as indicated over a 7-year period; grass cut when 4 to 5 inches high to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	100 lbs. 16% $NaNO_3$	1*	8	2,418
1929	375 lbs. 16% $NaNO_3$	2	6	3,819
1930	500 lbs. 16% $NaNO_3$	2	6	2,860
1931	750 lbs. 16% $NaNO_3$ (irrigated)	4	10	5,795
1932	875 lbs. 16% $NaNO_3$ (irrigated)	4	9	6,322
1933	1,000 lbs. $(NH_4)_2SO_4$, 500 lbs. 20% S. P., 200 lbs. KCl, 1,000 lbs. limate (irrigated)	7	9	6,598
1934	1,160 lbs. $(NH_4)_2SO_4$ (irrigated)	7	8	8,114

*Nitrogen was applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application was made the amounts applied each time were equally divided.

Yields were increased with each season as a result of irrigation and the use of increasingly liberal supplies of nitrogen (1,160 pounds of 20% ammonium sulfate per acre in 1934). It is doubtful if the plats have yet attained a maximum producing capacity. In 1934, yields were raised to a level far surpassing any which had been previously recorded. The turf on these areas has gradually thickened and improved, with no weed encroachment whatsoever.

TABLE 3.—*Total nitrogen, crude protein, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 1 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 19...	1,365.44*	3.32	20.75	0.90	2.42	15.13	0.75	0.69
June 4....	905.60	3.58	22.38	0.78	2.80	17.50	0.94	0.69
June 22...	1,112.00	3.34	20.88	0.86	2.48	15.50	0.92	0.60
July 10....	1,040.00	3.96	24.75	1.08	2.88	18.00	0.85	0.88
July 27....	1,228.80	3.62	22.63	0.86	2.78	17.25	1.28	0.76
Aug. 3....	1,020.00	4.08	25.50	1.12	2.96	18.50	1.26	0.76
Aug. 31...	751.87	4.26	26.63	1.44	2.82	17.63	1.15	0.92
Oct. 12....	690.14	2.84	17.75	0.74	2.10	13.13	1.01	1.09
Total and averages	8,114.00	3.63	22.66	0.97	2.65	16.58	1.02	0.79

*Nitrogen applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application was made the amounts applied each time were equally divided.

TABLE 4.—*Yields per acre of plat 2 variously fertilized and irrigated as indicated over a 7-year period; grass cut when 4 to 5 inches high to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yields in pounds per acre of oven-dried grass
1928	100 lbs. $NaNO_3$; 300 lbs. 20% S. P. 1 ton limestone; 150 lbs. KCl...	1*	9	2,953.80
1929	375 lbs. $NaNO_3$; 60 lbs. P_2O_5.....	2	6	5,284.00
1930	500 lbs. $NaNO_3$...............	2	6	3,097.60
1931	750 lbs. $NaNO_3$ irrigated........	4	10	6,622.00
1932	875 lbs. $NaNO_3$ irrigated........	4	9	6,741.60
1933	1,250 lbs. $NaNO_3$ irrigated.......	5	10	7,931.20
1934	1,160 lbs. $(NH_4)_2SO_4$ irrigated....	7	8	8,116.22

*Nitrogen applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application was made the amounts applied each time were equally divided.

While the amount of nitrogen used during the latter part of the experiment was excessive and not to be advised in pasture fertilization practices, it nevertheless demonstrates the remarkable efficiency of Kentucky bluegrass as a converter of nitrogen into increased yields

TABLE 5.—*Total nitrogen, total protein, true protein nitrogen, true protein, and non-protein nitrogen content of various cuttings of plat 2 for year 1934.*

Cutting dates	Pounds oven-dried grass per acre	Percentage total nitrogen	Percentage total protein	Percentage true protein nitrogen	Percentage true protein	Percentage non-protein nitrogen
May 19....	1,096.00	3.14	19.63	2.32	14.52	0.82
June 4.....	860.32	3.22	20.13	2.58	16.13	0.64
June 22....	978.56	3.22	20.13	2.36	14.75	0.86
July 10 . ..	1,236.52	3.54	22.13	2.46	15.38	1.08
July 27.....	1,401.86	3.32	20.75	2.64	16.50	0.68
Aug. 13....	891.12	3.98	24.88	3.00	18.75	0.98
Aug. 31....	814.08	3.74	23.38	2.56	16.00	1.18
Oct. 12.....	837.76	2.84	17.75	2.12	13.25	0.72
Total and averages	8,116.22	3.38	21.10	2.51	15.66	0.81

TABLE 6.—*Yields per acre of plat 3 variously fertilized and irrigated as indicated over a 7-year period; grass cut when 4 to 5 inches high to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	200 lbs. Calurea................	1*	9	3,237
1929	180 lbs. Calurea................	2	6	5,343
1930	240 lbs. Calurea................	2	6	3,403
1931	353 lbs. Calurea irrigated........	3	10	6,751
1932	412 lbs. Calurea irrigated........	4	9	7,340
1933	1,000 lbs. $(NH_4)_2SO_4$ irrigated....	5	10	8,238
1934	1,160 lbs. $(NH_4)_2SO_4$ irrigated....	7	8	8,093

*Nitrogen applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application was made the amounts applied each time were equally divided.

TABLE 7.—*Total nitrogen and total protein content of various cuttings of plat 3 for year 1934.*

Cutting dates	Pounds oven-dried grass per acre	Percentage total nitrogen	Percentage total protein
May 19.........................	1,175.04	3.42	21.38
June 4.........................	1,113.60	3.26	20.38
June 22.........................	1,214.40	3.16	19.75
July 10.........................	1,019.62	3.46	21.63
July 27.........................	1,198.90	3.60	22.50
Aug. 13.........................	835.20	4.20	26.25
Aug. 31.........................	702.24	4.08	25.50
Oct. 12.........................	834.40	3.18	19.88
Total and averages..............	8,093.40	3.55	22.16

TABLE 8.—*Yields per acre of plat 4 variously fertilized and irrigated as indicated over a 7-year period; grass cut when 4 to 5 inches high to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	100 lbs. $(NH_4)_2SO_4$	1*	8	1,969
1929	300 lbs. $(NH_4)_2SO_4$	2	6	2,901
1930	400 lbs. $(NH_4)_2SO_4$	2	6	2,334
1931	600 lbs. $(NH_4)_2SO_4$ irrigated	4	10	4,702
1932	700 lbs. $(NH_4)_2SO_4$ irrigated	4	9	5,445
1933	1000 lbs. $(NH_4)_2SO_4$ irrigated, 500 lbs. 20% S. P.; 1,000 lbs. limate; 200 lbs. KCl	5	9	6,084
1934	1,160 lbs. $(NH_4)_2SO_4$ irrigated	7	8	8,498

*Nitrogen applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application was made the amounts applied each time were equally divided.

TABLE 9.—*Total nitrogen and total protein content of various cuttings of plat 4 for year 1934.*

Cutting dates	Pounds oven-dried grass per acre	Percentage total nitrogen	Percentage total protein
May 19	1,234.24	2.92	18.25
June 4	937.44	3.36	21.00
June 22	978.56	3.16	19.75
July 10	1,202.24	2.98	18.63
July 27	1,156.60	3.52	22.00
Aug. 13	1,195.20	3.88	24.25
Aug. 31	1,026.43	4.10	25.63
Oct. 12	767.59	2.92	18.25
Total and averages	8,498.30	3.36	20.98

TABLE 10.—*Yields per acre of plat 5 variously fertilized and irrigated as indicated over a 4-year period; grass cut when 4 to 5 inches high to ground level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yields in pounds per acre of oven-dried grass
1931	500 lbs. 20% S. P.; 200 lbs. KCl 400 lbs. $(NH_4)_2SO_4$ irrigated	2*	8	6,954
1932	400 lbs. $(NH_4)_2SO_4$ irrigated	2	7	6,559
1933	1,000 lbs. $(NH_4)_2SO_4$ irrigated	5	8	8,690
1934	1,160 lbs. $(NH_4)_2SO_4$ irrigated	7	8	9,655.92

*Nitrogen applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application of nitrogen was made the amounts applied each time were equally divided.

TABLE 11.—*Total nitrogen, crude protein, non-protein nitrogen, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 5 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 19...	1,506.60	3.32	20.75	0.90	2.42	15.13	0.73	0.69
June 4....	1,222.00	3.58	22.38	0.78	2.80	17.50	0.94	0.69
June 22...	1,724.94	3.34	20.88	0.86	2.48	15.50	0.92	0.60
July 10....	1,113.90	3.96	24.75	1.08	2.88	18.00	0.85	0.88
July 27....	1,128.60	3.62	22.63	0.86	2.76	17.25	1.28	0.76
Aug. 13...	1,210.40	4.08	25.50	1.12	2.96	18.50	1.26	0.76
Aug. 31...	896.88	4.26	26.63	1.44	2.82	17.63	1.15	0.92
Oct. 12...	852.60	2.84	17.75	0.74	2.10	13.13	1.01	1.09
Total and averages	9,655.92	3.63	22.66	0.97	2.65	16.58	1.02	0.79

TABLE 12.—*Yields per acre of plat 6 variously fertilized and irrigated as indicated over a 4-year period; grass cut when 8 to 10 inches high to ground level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Yields in pounds per acre of oven-dried grass
1931*	500 lbs. 20% S. P.; 200 lbs. KCl; 400 lbs. $(NH_4)_2SO_4$ irrigated....	2†	6,954
1932	400 lbs. $(NH_4)_2SO_4$ irrigated	2	6,559
1933	1,000 lbs. $(NH_4)_2SO_4$ irrigated..	5	9,152
1934	1,160 lbs. $(NH_4)_2SO_4$ irrigated..	4	10,139

*Cut at 4- to 5-inch heights down to ground levels 1931 and 1932; cut at 8- to 10-inch heights down to ground level in 1933 and 1934.
†Where more than one seasonal application of nitrogen was made the amounts applied each time were equally divided.

TABLE 13.—*Total nitrogen, crude protein, non-protein nitrogen, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 6 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 19...	1,360.80	3.32	20.75	0.90	2.42	15.13	0.73	0.69
June 22...	2,677.20	2.52	15.85	0.64	1.88	11.75	0.80	0.64
July 27....	3,003.00	3.14	19.63	0.66	2.48	15.50	1.25	0.64
Aug. 31...	2,039.40	3.78	23.63	1.16	2.62	16.38	1.01	0.84
Oct. 12....	1,058.20	2.86	17.88	0.70	2.16	13.50	0.94	0.92
Total and averages	10,138.00	3.12	19.54	0.81	2.31	14.45	0.95	0.74

TABLE 14.—*Yields per acre of plat 7 variously fertilized and irrigated as indicated over a 7-year period; grass cut when 4 to 5 inches high down to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	300 lbs. 20 %S. P.; 150 lbs. KCl; 1 ton limestone	0	8	1,843.6
1929	300 lbs. 20% S. P.	0	6	3,438.4
1930		0	6	1,218.4
1931		0	10	2,641.6
1932	400 lbs. $(NH_4)_2SO_4$ irrigated	2*	8	4,995.2
1933	400 lbs. $(NH_4)_2SO_4$ irrigated	2	8	5,548.0
1934	750 lbs. 20% S. P.; 200 lbs. KCl; 1,000 lbs. $(NH_4)_2SO_4$ irrigated	6	7	7,281.5

*Nitrogen applied after each removal of grass because yields diminish more rapidly and progressively unless this practice is followed. Where more than one seasonal application of nitrogen was made the amounts applied each time were equally divided.

TABLE 15.—*Total nitrogen, crude protein, non-protein nitrogen, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 7 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 24	1,199.9	2.80	17.50	0.56	2.24	14.00	0.69	0.63
June 16	1,080.7	2.80	17.50	0.82	1.98	12.58	1.67	0.92
July 10	1,372.3	2.84	17.75	0.76	2.08	13.00	1.35	0.84
July 27	1,107.1	3.08	19.25	0.52	2.56	16.00	1.04	0.62
Aug. 13	882.0	4.08	25.50	1.04	3.04	19.00	1.28	0.71
Aug. 31	854.5	4.02	25.13	1.28	2.74	17.13	1.01	0.91
Oct. 12	785.0	2.88	18.00	0.64	2.24	14.00	0.98	1.15
Totals and averages	7,281.5	3.21	20.09	0.80	2.41	15.10	1.15	0.83

TABLE 16.—*Yields per acre of plat 8 variously fertilized and irrigated as indicated over a 7-year period; grass cut when 4 to 5 inches high down to 1½ inch level.*

Year	Treatment on acre basis	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	300 lbs. 20% S. P.; 150 lbs. KCl; 1 ton limestone	8	1,843.6
1929	300 lbs. 20% S. P.	6	3,438.4
1930		6	1,218.4
1931		10	2,641.6
1932	Irrigated	8	2,557.6
1933	Irrigated	8	2,079.2
1934	750 lbs. 20% S. P.; 200 lbs. KCl irrigated	7	2,367.82

TABLE 17.—*Total nitrogen, crude protein, non-protein nitrogen, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 8 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 24..	230.40	2.30	14.38	0.44	1.86	11.63	0.76	0.70
June 16...	313.00	2.26	14.13	0.68	1.58	9.88	1.10	0.83
July 10. .	364.42	2.26	14.13	0.56	1.70	10.63	1.10	0.63
July 27 ..	401.20	2.84	17.75	0.50	2.34	14.63	1.56	0.78
Aug. 13..	329.47	3.40	21.25	0.82	2.58	16.13	1.47	0.92
Aug. 31..	269.31	3.56	22.25	0.50	3.06	19.13	1.28	0.95
Oct. 12 ..	459.98	3.44	21.50	0.92	2.52	15.75	1.01	1.89
Total and averages	2,367.82	2.87	17.91	0.63	2.23	13.97	1.18	0.96

TABLE 18.—*Yields per acre of plat 9 variously fertilized and irrigated as indicated over a period of 7 years; grass cut when 4 to 5 inches high to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	None......	0	8	1,051.72
1929	None	0	6	2,113.60
1930	None	0	6	912.00
1931	None	0	5	1,504.80
1932	250 lbs. $(NH_4)_2SO_4$ irrigated. .	1*	7	2,905.60
1933	400 lbs. $(NH_4)_2SO_4$ irrigated .	2	9	5,344.80
1934	680 lbs. $(NH_4)_2SO_4$ irrigated .	4	5	4,476.46

*Nitrogen applied after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application of nitrogen was made the amounts applied each time were equally divided.

TABLE 19.—*Total nitrogen, crude protein, non-protein nitrogen, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 9 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 26...	684.72	2.84	17.75	0.54	2.30	14.38	0.82	0.67
June 22...	696.00	1.98	12.38	0.22	1.76	11.00	0.57	0.60
July 27....	1,179.36	2.48	15.50	0.36	2.12	13.35	0.78	0.69
Aug. 27...	977.63	3.26	20.38	0.60	2.66	16.63	0.80	0.88
Oct. 12....	938.75	3.02	18.88	0.76	2.26	14.03	0.60	1.06
Total and averages	4,476.46	2.72	16.98	0.50	2.22	13.88	0.71	0.78

TABLE 20.—*Yields per acre of plat 10 variously fertilized and irrigated over a 7-year period; grass cut when 4 to 5 inches high to 1½ inch level.*

Year	Treatment on acre basis	Number of applications of nitrogen per year	Number of cuttings	Yield in pounds per acre of oven-dried grass
1928	None	0	8	1,051.72
1929	None	0	6	2,113.60
1930	None	0	6	912.00
1931	None	0	5	1,504.80
1932	500 lbs. 20% S. P.; 200 lbs. KCl 250 lbs. $(NH_4)_2SO_4$ irrigated	1*	7	2,858.80
1933	400 lbs. $(NH_4)_2SO_4$ irrigated	2	9	6,197.80
1934	500 lbs. 20% S. P.; 680 lbs. $(NH_4)_2SO_4$ irrigated	4	5	5,412.58

*Nitrogen appled after each removal of grass because yields diminish rapidly and progressively unless this practice is followed. Where more than one seasonal application of nitrogen was made the amounts applied each time were equally divided.

TABLE 21.—*Total nitrogen, crude protein, non-protein nitrogen, true protein nitrogen, true protein, P_2O_5, and CaO content of various cuttings of plat 10 for year 1934.*

Cutting dates	Lbs. oven-dried grass per acre	Percentage total nitrogen	Percentage crude protein	Percentage non-protein nitrogen	Percentage true protein nitrogen	Percentage true protein	Percentage P_2O_5	Percentage CaO
May 26	1,027.20	2.72	17.00	0.56	2.16	13.50	0.71	0.74
June 22	669.60	2.22	13.88	0.62	1.60	10.00	0.98	0.70
July 27	1,404.29	2.72	17.00	0.52	2.20	13.75	1.08	0.62
Aug. 27	1,338.05	3.10	19.38	0.50	2.60	16.25	1.12	0.77
Oct. 12	973.44	3.00	18.75	0.74	2.26	14.03	0.85	1.05
Total and averages	5,412.58	2.75	17.20	0.59	2.16	13.51	0.95	0.78

and crude protein. As indicated in Tables 2 to 9, inclusive, the minimum yield in 1928, the first year of the experiment, for grass cut regularly when 4 to 5 inches high to a 1½ inch level was 1,969 pounds of oven-dried grass per acre and the maximum 3,237 pounds. The minimum yield in 1931, the first year of irrigation, was 4,702 pounds and the maximum 6,751 pounds. In 1934 the minimum yield was 8,093 pounds and the maximum 8,498 pounds. Under a system of increased nitrogen fertilization, irrigation, and proper management, the turf on these areas has thickened and improved to a point where in 1934 it was producing approximately three times as much dry grass per acre as in 1928. A measure of the increased yield attributable to irrigation is not possible because the amount of nitrogen used from year to year was not constant. However, in other studies not herein reported annual yields during the period 1930 to 1934 were doubled in every case where water and nitrogen were compared to nitrogen alone.

Evidence is also available to show that Kentucky bluegrass cut when 4 to 5 inches high to ground level has continuously outyielded grass cut when 4 to 5 inches high to 1½ inch levels. Through a 4-year period beginning in 1931 and ending in 1934, differences favoring close cutting with the exception of the year 1932 have become progressively greater. In 1934, as shown in Table 10, this area, treated the same with respect to fertility treatment and irrigation but cut to ground level, produced, 9,656 pounds of oven-dried grass per acre as compared to 8,205 pounds, which is an average of plats 1, 2, 3, and 4 cut to 1½ inch levels during the same period. This figure represents a difference of 1,451 pounds of oven-dried grass per acre in favor of cutting to ground level. Under a system of optimum moisture and fertility, centering around large, frequent applications of nitrogen and with no consideration for cost, this method of management offers what would appear to be a means of securing maximum yields without subsequent injury. The reasons for the difference in yield favoring a system of close cutting are not entirely clear. These differences may be accounted for largely by the more complete defoliation resulting from a system of close cutting. If the grass grew 5 inches tall, an uncut remnant of 1½ inches would represent about 30% of the growth measured on a linear basis. New growth of the grass leaves coming from buds on the rhizomes would have to produce 1½ inches of linear growth before they would be harvested at all.

In previous work, Graber (10)[4] has shown that blue-grass given 13 clippings in 1929 at a level of a ½ inch produced 54% more dry weight than bluegrass cut 13 times at a level of 1½ inches. This grass was abundantly fertilized with nitrogen. Where no nitrogen was applied the grass cut closely 13 times produced 156% more dry weight than the grass cut at the 1½-inch level. Moreover, Graber measured the after-effects of frequent and close cutting in 1930. Very substantial reductions in yield occurred with close clippings where the grass was never permitted to grow more than 2 or 3 inches tall before removal. No such reductions are apparent in these trials where the grass was always allowed to grow to 4- to 5-inch heights before removal to ground level. However, it appears that factors other than the one mentioned above may be operative in bringing about the increase favoring the system of close cutting and growth recovery used in these trials. No actual counts were made, but preliminary observations show more young leaves on the closely cut plats than on the plats cut to 1½ inch levels. Furthermore, an examination of the rhizomes from the closely cut plats shows that under a system of close cutting management, they are smaller, shorter, and much more branched than on the normally cut (1½ inch) areas.

There has been no weed encroachment whatsoever during this period, the stand being composed entirely of Kentucky bluegrass. The rapid return of a leaf surface under these close cutting conditions suggests an exceedingly efficient photosynthetic activity, capable of maintaining the plant in excellent vigor during the growing season and permitting such storages as may be necessary to renew growth

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[4]Figures in parentheses refer to "Literature Cited", p. 532.

each spring. Over a period of years, close cutting, with a subsequent rest period permitting the grass to make a 4- to 5-inch return growth appears, under the conditions of this experiment, to be a means of increasing the thickness of coverage to a point which makes possible the highest maximum seasonal yields, without signs of visible injury. At present plans for a more complete experiment are being laid out to determine the cutting or grazing stage (height of growth), as well as the closeness of grazing, which may be practiced which will insure a maximum productivity of bluegrass without subsequent injury. Yield records of grass cut frequently and close will be compared with less severe and drastic treatments until such time as reliable conclusions are forthcoming.

In order to determine the effect upon yield of a longer rest or recovery period, an experiment was begun in 1933 in which one plat was permitted to grow to a 4- to 5-inch height and then cut to ground level and the other plat allowed to grow 8 to 10 inches tall and cut in the same way. The results are presented in Tables 10 and 12. The objective of this study was to determine if a longer rest period would yield more grass, or inversely, if cutting when the grass is 4 to 5 inches high to ground level, results in any form of injury as measured by decreased yields. In the light of previous investigations in Wisconsin (10, 11, 12, 13) and elsewhere (14), evidence is available which indicates that frequent and close defoliations of bluegrass may effectively reduce food storages in the rhizomes to a level where it clearly becomes the limiting factor of growth. No such reductions in yield were forthcoming under the conditions of this trial. The grass permitted to grow to 8- to 10-inch heights and then cut to ground level yielded only 462 pounds per acre or 5.3% more oven-dried grass in 1933 and 483 pounds or 5.3% more in 1934 than the plat cut to ground level when the grass was 4 to 5 inches high. This increase favoring a longer growth or recovery period is a comparatively insignificant one due in part to the fact that the dense, foliar growth of the taller, irrigated, and heavily fertilized grass has resulted in the shading and killing of much of the bottom growth with a consequent thinning of the turf. It is also important to bear in mind that increased yields due to cutting when the grass is 8 to 10 inches high as compared to cutting when it is 4 to 5 inches high may be offset in part by a corresponding increase in crude fiber and decreased palatability, digestibility, percentage protein, and nutritive value. The yields in 1934 for the grass cut when 8 to 10 inches high to ground level (10,139 pounds of oven-dried grass per acre) and for the grass cut when it was 4 to 5 inches high to ground level (9,656 pounds of oven-dried grass per acre) are believed to be the highest ever recorded for Kentucky bluegrass.

While the first consideration of pasture fertilization should be the mineral requirements of the soil, the use of nitrogen is of fundamental importance in the management of grass lands. This is shown by the data presented in Tables 16 and 18 in which the results from complete mineral fertilization with and without nitrogen for 1932, 1933, and 1934 are given. A completely fertilized plat produced 4,995 pounds of oven-dried grass an acre in 1932 as compared with 2,558 pounds

from a corresponding mineral-treated plat. This represents a 95% increase in favor of nitrogen. In 1933 and 1934 the average acre yields of oven-dried grass were 5,548 and 7,282 pounds, respectively, for the plat given complete fertilization as compared with 2,079 and 2,368 pounds for the mineral-treated area, or in other words, an increase of 119 and 207% in 1933 and 1934. It is clear that a system of management which does not include nitrogen fertilization or some other source of nitrogen, cannot be expected to increase yields appreciably. Where moisture is not a limiting factor of growth, the effect of nitrogenous fertilization in increasing the productivity of pastures consists of causing more herbage to grow at those times when production is ordinarily low, namely, in early spring and late fall, and to increase markedly the yield during the rest of the growing season. Numerous other investigators (5, 7, 9, 15, 18, 19, 20, 21, 22, 24, 25, 26) have recorded similar results.

In Tables 18 and 20 a comparison is made between yields obtained with nitrogen alone and complete mineral fertilization including nitrogen. In 1933, complete fertilization gave an increase in yield of 16% when compared with the plat receiving nitrogen alone, and in 1934, 21%. From these data it is apparent that on soils which are deficient in phosphorus and potash, nitrogen does not operate with the highest degree of efficiency, unless it is supported by carriers of phosphorus and potash.

Under any system of repeated cuttings or grazings, the capacity of a plant to maintain its productivity becomes a function of two distinct and separate abilities, first, to remain healthy and vigorous despite the treatment; and second, to start growing immediately after each cutting or grazing and to grow rapidly during each incremental period. The best yielding pasture plants will therefore be those having a high degree of persistency and a capacity for a quick "pick-up." Kentucky bluegrass has much inherent persistency, but only a quick "pick-up" when such factors as adequate moisture, optimum temperature, and high soil fertility (nitrogen at a high plane) prevail.

CHEMICAL ANALYSIS OF OVEN-DRIED GRASS

Calcium and phosphorus.—The results obtained during the 1934 season are presented, because they are typical and representative of the figures obtained during the entire 7-year period. The results of the chemical analysis appear in Tables 2 to 21, inclusive. On all of the irrigated areas the P_2O_5 percentage content was found to be lowest during the period of rapid growth usually referred to as "flush growth" in the spring; attained a maximum in July and early August, when growth is retarded somewhat by high temperatures; and dropped with the return of growth during the cooler fall weather. On the other hand, there was a uniform seasonal rise in the CaO content from the beginning to the end of the growing season. These seasonal variations are in general accord with the results of other work appearing in the literature (1, 2, 3, 4, 6, 7, 8, 16, 17, 21, 23, 24, 25, 26). No attempt has been made to explain these variations in pure grass cultures. From the standpoint of these results and many others of a similar

nature, the grass is clearly of the poorest quality with respect to phosphorus and calcium during the early spring period when the greatest amount of vegetative growth is being made.

The stage of growth or nearness to maturity of the plant is also a factor of considerable importance in influencing the P_2O_5 and to a lesser extent the CaO percentage content of the herbage. In another study not reported here the P_2O_5 percentage content was found to vary inversely with the stage of maturity of the plant, being highest in young, actively growing grass, and decreasing to about one-half the original percentage content at maturity. The decrease in calcium was not as marked. As shown in Tables 11 and 13, grass permitted to grow to 8- to 10-inch heights was found to be appreciably lower in both phosphorus and calcium than grass cut when 4 to 5 inches high.

From a study of Tables 15 and 17 it would also appear that nitrogen has a tendency to depress the calcium and to a lesser extent the phosphorus content of the herbage. The highest seasonal average percentage content for both calcium and phosphorus is found on an area not receiving nitrogen. However, it is believed that this high calcium and phosphorus percentage content is due to the natural ingress of white clover which is normally higher in calcium and phosphorus content than Kentucky bluegrass. The greater total yield of dry matter removed from nitrogen-fertilized grasses, however, carries with it a larger amount of total phosphorus and calcium than does grass which is not so treated, but the average percentage content is not increased, and is often decreased, where nitrogen fertilizers are used in conjunction with carriers of phosphorus and calcium.

That the application of phosphorus to the soil is strikingly reflected in the chemical composition of the herbage is shown in Tables 19 and 20. The completely fertilized plat had an average percentage content of 0.95 for phosphorus, as compared to 0.71 where nitrogen was used alone.

Nitrogen.—In general, the data show that a high nitrogen content of pasture vegetation may be obtained by the use of readily available nitrogenous fertilizers, and that these high levels can be maintained only if nitrogen is applied at frequent intervals throughout the growing season. The average total nitrogen content for all areas receiving 1,160 pounds per acre of ammonium sulfate was 3.45% nitrogen or 21.51% crude protein; for those given 1,000 pounds, 3.21% nitrogen or 20.09% crude protein; for those receiving 680 pounds, 2.74% nitrogen or 17.07% crude protein; and for the complete mineral treatment, 2.87% nitrogen or 17.91% crude protein. The high protein content of vegetation on the mineral-treated area which did not receive nitrogen is due to the presence of white clover. It is evident from these results that the nitrogen content of the herbage is appreciably affected by the addition of nitrogen carriers to the soil and that it varies according to the amount of nitrogen added.

From Tables 19 and 21 it is also clear that the nitrogen content of the herbage may be increased by applications of phosphorus and potassium to the soils. Other workers have recorded similar results (6, 23). Also, from Tables 11 and 13 it is evident that the nitrogen

content of grass 8 to 10 inches tall is lower than that of grass 4 to 5 inches tall, and as shown in Table 22, although the acre yield of the taller grass is higher, the crude protein produced per acre is lower, due to less nitrogen in the herbage.

TABLE 22.—*Pounds of crude protein produced an acre in 1934; all areas irrigated.*

Plat No.	Treatment on acre basis in 1934 for various plats	Yield in pounds of dry matter an acre	Average percentage crude protein	Pounds crude protein produced an acre
9	680 lbs. $(NH_4)_2SO_4$	4,476	16.98	760
10	500 lbs. 20% S. P.; 680 lbs. $(NH_4)_2SO_4$....	5,413	17.20	931
2	1,160 lbs. $(NH_4)_2SO_4$.......	8,116	21.10	1,712
5	1,160 lbs. $(NH_4)_2SO_4$... ...	9,656	22.66	2,188
6	1,160 lbs. $(NH_4)_2SO_4$	10,139	19.54	1,981
7	750 lbs. 20% S. P.; 200 lbs. KCl; 1,000 lbs. $(NH_4)_2SO_4$	7,282	20.09	1,463
1	1,160 lbs. $(NH_4)_2SO_4$	8,114	22.66	1,839
3	1,160 lbs. $(NH_4)_2SO_4$	8,093	22.16	1,793
4	1,160 lbs. $(NH_4)_2SO_4$	8,498	20.98	1,783
8	750 lbs. 20% S. P.; 200 lbs. KCl.....	2,368	17.91	424

Most striking, however, are the results appearing in Table 22 in which the acre production of crude protein for the various fertilizer treatments is recorded. Only 424 pounds of crude protein an acre were produced on the area given complete mineral fertilization but no nitrogen; an average of 1,883 pounds on those given 1,160 pounds of ammonium sulfate; 1,463 pounds on the one to which 1,000 pounds was applied; and an average of 846 pounds on those given 680 pounds.

The form or forms of protein existing in heavily fertilized grass have raised many significant questions in recent years. At present a discrimination is made only between protein and non-protein nitrogen. The relative merits of these two forms of nitrogen have not been determined. It is generally assumed, but it is not definitely known, that the non-protein nitrogen is utilized by the animal and functions in protein metabolism in a manner similar to true protein compounds.

In order to determine the effect of nitrogen fertilization on the relative proportions of protein and non-protein forms of nitrogen in the plant, individual cuts from various plats were subjected to a fractional nitrogen analysis. The results of the analysis appear in Tables 2 to 21, inclusive.

The average total nitrogen content of the herbage for 1934 from all areas given 1,160 pounds of ammonium sulfate was 3.45% or 21.51% crude protein. Of this amount 0.80%, or 25.8% of the total nitrogen, was found to exist in the plant in a non-protein form. The total nitrogen content of the herbage from the area which was given 1,000 pounds of ammonium sulfate was 3.21% or 20.09% crude protein. Of the total nitrogen, 24.9% was in a non-protein form (0.89%).

To the area to which was added 680 pounds of ammonium sulfate, there was found present in the herbage a total nitrogen content of 2.74% or 17.07% crude protein. Of the total nitrogen 20.1% existed in a non-protein form (0.55%). The average total nitrogen content of the herbage from the area given complete mineral fertilization but no nitrogen was 2.87% or 17.91% crude protein. Of this amount 0.63%, or 21.9% of the total nitrogen present, was in a non-protein form. From these data it is apparent that the non-protein organic form of nitrogen is higher where large applications of nitrogen are made than where it is used in smaller amounts or not at all.

True protein nitrogen gave as a seasonal average, 2.53% or 15.82% true protein in the grass from the areas given 1,160 pounds of ammonium sulfate; 2.41% or 15.10% true protein in the herbage on the plat receiving 1,000 pounds; 2.19% or 13.70% true protein from that given 680 pounds of ammonium sulfate; and 2.23% or 13.97% true protein in the grass from the area given complete mineral fertilization but no nitrogen. Generally, the percentage of true protein is highest where large applications of nitrogen are made even though the percentage of non-protein nitrogen is also higher on these areas. This is good evidence that nitrogen is rapidly converted to the more complex forms within the plant even under systems of management demanding the use of large and frequent applications of nitrogen fertilization.

Nitrogen recovery from permanent bluegrass pastures.—One of the outstanding merits of nitrogen fertilization on Kentucky bluegrass pastures is found in its relatively high seasonal recovery as crude protein in the grass. When moisture is not a limiting factor of growth, the recovery of fertilizer nitrogen in the form of crude protein is high, ranging, as is evident from a study of Table 23, from 39.5% to 121.7%, or an average of 87.6% for all plats receiving nitrogen. The low recovery of 39.5% on plat 9 is due, no doubt, to the fact that phosphorus was not used in conjunction with nitrogen fertilization. It would appear from these results that where phosphorus is a limiting factor of soil fertility, applied nitrogen does not operate with the highest degree of efficiency due primarily to a lower acre yield and to a lower nitrogen content of the vegetation removed. It will be noted in Table 23 that in two instances the percentage recovery of nitrogen applied as ammonium sulfate is more than 100. This is no doubt due to the fact that at present there is no known means of determining the exact amount of nitrogen removed from the soil itself. It is evident from the results, however, that a very high rate of protein synthesis is possible by heavily manuring grass with soluble nitrogenous compounds, even when they are used in excessive and very impractical amounts.

SUMMARY

A field study pertaining to the influence of fertilization, irrigation, and stage and height of cutting on the yield and composition of bluegrass has been in progress at Madison, Wis., for 7 years, 1928 to 1934, inclusive. Approximately 80 plats were involved in this investigation, but for convenience of presentation results from only 10

TABLE 23.—*Nitrogen recovery from intensively fertilized permanent bluegrass pastures for 1934; irrigated.*

Plat No.	Treatment on acre basis in 1934 for various plats	Potential protein value of nitrogen applied in pounds	Pounds of crude protein produced an acre	Pounds of crude protein increase over check	Percentage recovery of nitrogen applied
9	680 lbs. $(NH_4)_2SO_4$...	850	760	336	39.5
10	500 lbs. 20% S. P.; 680 lbs. $(NH_4)_2SO_4$	850	931	507	59.7
2	1,160 lbs. $(NH_4)_2SO_4$..	1,450	1,712	1,288	88.8
5	1,160 lbs. $(NH_4)_2SO_4$..	1,450	2,188	1,764	121.7
6	1,160 lbs. $(NH_4)_2SO_4$.	1,450	1,981	1,557	107.4
7	750 lbs. 20% S. P. 200 lbs. KCl 1,000 lbs. $(NH_4)_2SO_4$	1,250	1,463	1,039	83.1
1	1,160 lbs. $(NH_4)_2SO_4$	1,450	1,839	1,415	98.3
3	1,160 lbs. $(NH_4)_2SO_4$.	1,450	1,793	1,369	95.1
4	1,160 lbs. $(NH_4)_2SO_4$.	1,450	1,783	1,359	94.4
8*	750 lbs. 20% S. P. 200 lbs. KCl	——	424	——	——

*Considered as a check because it was not given nitrogen fertilization.

typical and representative plats are presented in this paper. The results are summarized as follows:

1. Nitrogen in an available form and water were found to be the two most important limiting growth factors under the conditions of these experiments. Mineral fertilization alone gave only small increases in yield. Nitrogen used in conjunction with mineral fertilization and irrigation consistently doubled, and in some instances trebled, the yield of grass. Water alone, during the period of 1930 to 1934 doubled yields. Nitrogen alone did not give maximum increases unless it was supported by mineral fertilization.

2. When the grass was cut to ground level (as closely as is possible with a lawn mower) higher seasonal yields were obtained than when it was cut at a higher level (1½ inches). In 1934, grass cut to ground level produced 9,656 pounds of oven-dried grass per acre as compared to 8,205 pounds, which is the average of grass from plats 1, 2, 3, and 4 cut at 1½ inch level during the same period.

3. Grass cut when 8 to 10 inches high to ground level gave only slightly greater increases in yield than that cut when 4 to 5 inches high to ground level. Only 5.3% increase in yield favoring the taller growing grass was recorded in 1933 and 1934.

4. When moisture is not a limiting factor of growth, the P_2O_5 content of grass cut regularly is lowest during the early spring, attains a maximum in July and August, and drops slightly in the fall. There is a uniform rise in CaO content from spring to fall.

5. Grass cut when 8 to 10 inches high was found to be appreciably lower in P_2O_5 and CaO content than grass cut when 4 to 5 inches high.

6. Nitrogen fertilization lowered the CaO and P_2O_5 content of the grass. Phosphate fertilization increased the phosphorus content of the grass to an appreciable extent.

7. Grass of high nitrogen content is produced only where frequent applications of nitrogen are made throughout the growing season. The percentage nitrogen content of the herbage was found to vary directly with the amount of nitrogen fertilizer applied.

8. The nitrogen content of herbage may be increased by the application of phosphorus and potash to the soil.

9. The nitrogen content of herbage decreases as the plant approaches maturity.

10. The crude protein produced per acre was found to vary directly with the amount of nitrogen fertilizer applied. The plat given 1,160 pounds of ammonium sulfate per acre produced 4.44 times more crude protein than did the plat which was not fertilized with nitrogen.

11. The percentage of non-protein, water-soluble nitrogen was found to vary directly with the amount of nitrogen fertilizer applied. Of the total nitrogen on the plat given 1,160 pounds of ammonium sulfate per acre, 25.8% was in a non-protein, water-soluble form, whereas 21.9% of the total nitrogen on the plat given mineral fertilization but no nitrogen was in this form.

12. The percentage of true protein was found to vary directly according to the rate of application of ammonium sulfate.

13. The recovery of fertilizer nitrogen, when moisture was not a limiting factor of growth, was high, ranging in 1934, as is evident from a review of the data, from 39.5 to 121.7%, or an average of 87.6% for all plats receiving nitrogen.

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SIZE OF PLAT AND NUMBER OF REPLICATIONS NECESSARY FOR VARIETAL TRIALS WITH WHITE PEA BEANS[1]

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MANY experiments have been conducted with different field crops to determine what size of plat and how many replications are necessary to give reliable results in the conducting of varietal trials. Economical administration of funds requires that the plats be small and repeated a minimum number of times. Efficient plat technic, however, requires that the plats be of sufficient size and repeated often enough to make the results dependable.

That information obtained for one crop under certain conditions cannot be applied to another has been clearly shown. A complete bibliography (1)[3] of articles dealing with plat technic in general was reported by a committee of the American Society of Agronomy for the standardization of field experiments. Additional articles (2) were recently reported. A search of this literature fails to reveal any experiments of this nature with white pea beans (*Phaseolus vulgaris* L.).

Odland and Garber (4) in their work with soybeans, which comes nearest to this particular subject, concluded that under conditions existing where their experiment was conducted, a 16-foot plat one row wide replicated three times was the most satisfactory when both accuracy and economy of land and of labor were taken into consideration.

The object of the study reported in this paper was to find the proper size of plat and the number of replications of this size necessary for varietal trials with white pea beans when the trials are conducted under conditions similar to those prevailing in this experiment. Due consideration should be given to the amount of land to be used and to the convenience of handling the plats in all field operations.

MATERIAL AND METHODS

The Robust variety of white pea beans is used as a standard of comparison in variety trials at the Michigan Agricultural Experiment Station and is grown extensively throughout the state. Consequently, it was used in this experiment. An area of Conover soil of approximately 1¾ acres, located in one of the regular plant breeding sections, was chosen for the planting. The beans were planted in rows 28 inches apart on June 15, 1932, and so spaced that the plants were approximately 1 to 2 inches apart. To insure a good stand, 60 pounds of beans were planted to the acre instead of the usual rate of 45 pounds. After the last cultivation, an area 210 feet long and 210 feet wide was chosen from the center of the

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[3]Figures in parenthesis refer to "Literature Cited", p. 547.

field for the experiment. A total of 1,890 plats was obtained by dividing this area into 21 10-foot series, each 90 rows wide. A count of the number of plants in each 10-foot plat was made shortly before harvest. At maturity the plants were pulled by hand and allowed to cure. The 10-foot plats were threshed and the beans air dried in a warm room before weighing. Fortunately, the season was favorable for beans and all plats had a good stand without any skips, although a fairly wide range in the number of plants per row occurred. The coefficient of correlation between stand and yield was found to be .10 ± .01. This coefficient was too small to warrant making any correction in the yields for variations in stand.

The statistical constants used to study the problems were obtained by making use of the "analysis of variance" as suggested by Immer (3). The principles of the method as stated by Immer are: "If the total variability of the observations on all the plots is given in suitable terms (sum of squares) it may legitimately be apportioned to various known causes, leaving a remaining portion ascribable to uncontrolled or unknown causes. The latter will then serve as a basis for the calculation of the error of the experiment. The variance (standard deviation squared) due to any of the known causes or to the uncontrolled or unknown causes may then be found by dividing the sum of squares by the appropriate number of degrees of freedom. The term 'degrees of freedom' is here used in the sense of 'independent comparisons'. With n quantities whose mean is fixed, there are in general n — 1 independent comparisons or degrees of freedom."

The assumption was made that five varieties or treatments were to be tested by the analysis and that the arrangement of the plats within each replication was at random. Thus, variation between blocks could be removed legitimately from the total variation by subtracting the sum of squares due to variation between blocks from the total sum of squares of all of the plats. The remainder is due to variation within blocks. The standard error, calculated from this remainder, was used as the error of the experiment. This error will be smaller than the standard error as calculated from the total population only when the variation between blocks is greater than that within blocks.

EXAMPLE OF ANALYSIS OF VARIANCE FOR ENTIRE PLAT

An example of the analysis of variance as applied to yields of the 1,890 plats 10 feet long and 1 row wide is given in Table 1.

TABLE 1.—*Analysis of variance of yield of beans in plats 10 feet long and 1 row wide for 21 series.*

Variation	Degrees of freedom	Sum of squares	Variance or mean square	Standard deviation	F*	Error in % of mean yield
Between blocks	377	6,967,077.18	19,678.48	140.28	——	——
Within blocks .	1,512	4,879,158.20	3,226.96	56.80	6.10	12.67
Total between plats	1,889	11,846,235.38	6,271.16	79.20	——	——
Mean (M) = 448.38.						

*The ratio of the larger mean square to the smaller.

The formula used to obtain the total sum of squares was $S(X^2) - S(X)M_x$, where X represents a variate and M_x the mean of the population. This formula

was briefed to S (X^2) — C, where C (correction) represents S (X) M_x. The formula for the sum of squares between blocks was $\frac{S(B^2)}{5} - C$ in which B was the sum of the five plats in a block and C was the correction term S (X) M_x. The sum of B^2 was divided by 5 to place the value on a single plat basis.

The total sum of squares 11,846,235.38 was obtained by subtracting C, or 379,966,062.62, from S (X^2), or 391,812,298.00. The sum of squares between the 378 blocks of five adjacent plats added sidewise of the series was obtained in a similar way, except the summation was divided by 5, to place values on the basis of a single plat, before subtracting the correction factor. Thus, $\frac{S(B^2)}{5} - C$ became $\frac{1,934,665,699.00}{5} - 379,966,062.62$ which gave 6,967,077.18. The sum of squares due to variation within blocks was the difference between the total sum of squares and that portion due to variation between blocks. Since the total of 1,890 plats was considered, there were 1,889 (N — 1) degrees of freedom attributable to the total sum of squares. There were 378 blocks (of five plats each) and consequently 377 (N — 1) degrees of freedom due to blocks. The difference of 1,512 was the number of degrees of freedom due to variation between the five plats within each of the 378 blocks. Each sum of squares was divided by its respective number of degrees of freedom to give the mean square. The standard error, the square root of the mean square, calculated from the remainder was 56.80 grams or 12.67% of the mean yield of 448.38 grams.

The significance of the difference between the variance between blocks and that within blocks was determined by the F test developed by Snedecor (5). The values of F in these tables are given for two different levels of significance, the 5% and the 1% points for selected numbers of degrees of freedom. The former is expected to be exceeded in random sampling from a homogeneous population 5 times in 100 trials, the latter only once. The 5% point is taken as a convenient minimum level of significance. In Table 1 the observed value of F exceeds the 1% point and it can be concluded that removal of the variation between blocks was worth while.

EXAMPLE OF ANALYSIS OF VARIANCE FOR CENTER ROWS OF PLAT

The standard error of a 3-row plat was determined with the outer rows discarded to eliminate possible competition from other plats. The center values were used from each 3-row plat. The analysis of variance is given in Table 2.

TABLE 2.—*Analysis of variance of yield of beans in 3-row plats 10 feet long of which only the center row was used for 21 series.*

Variation	Degrees of freedom	Sum of squares	Variance or mean square	Standard deviation	F	Error in % of mean yield
Between blocks	125	2,277,829.65	18,222.64	134.99	—	—
Within blocks..	504	1,887,275.60	3,744.59	61.19	4.87	13.40
Total between plats.......	629	4,165,105.25	6,707.64	81.90	—	—

M = 456.73

The number of degrees of freedom attributable to total variation was 629 since there were 630 3-row plats in the entire field of 1,890 single rows, 10 feet long.. Each block of five then required 15 rows. The 630 3-row plats subdivided into blocks of five contributed 125 degrees of freedom, leaving 504 degrees of freedom attributable to variation between plats within blocks.

The observed value of F exceeded the 1% point and it was concluded that the removal of the variation between blocks was worth while.

The standard error of a single plat was 61.19 grams or 13.40% of the mean yield (456.73 grams) of all the central rows in the 3-row plats in the field.

RESULTS AND DISCUSSION

The weights in grams of cleaned beans for the 1,890 plats are given in Table 3. Analyses were made of the fields of plats 1, 2, 3, 4, 5, 6, 9, and 18 rows wide and 10, 20, 30, 40, and 50 feet in length, respectively. A total of 108 different sizes and shapes of plats was studied, 72 of these involved the entire plat while the other 36 used only the center rows, the outside or border rows being discarded to eliminate competition between plats. Certain of these combinations could not be based on the entire area of 21 series and 90 rows wide. This was partially due to the original assumption involving five varieties of treatments. The 4-row and 5-row plats could not use all 90 rows because 90 is not divisible by 4, nor could the 18 plats 5 rows wide be subdivided into blocks containing five plats each. Also, 21 series could not be subdivided into plats 20, 40, or 50 feet in length, but could be divided into plats 30 feet in length. To overcome these limitations, values were calculated for areas 21 and 20 series in length containing 90, 80, and 75 rows in width. In order to compare the values obtained with plats 4 and 5 rows wide with those 1, 2, 3, 6, 9, and 18 rows wide, the standard errors were also calculated for the areas 21 and 20 series long, and 80 and 75 rows wide, respectively. The same conditions hold true for the plats having the border rows discarded. Similar calculations were made whenever necessary.

STANDARD ERRORS IN PERCENTAGE OF MEAN

The standard deviations, as obtained by analysis of variance for the plats of varying lengths and widths, were expressed in percentage of their respective means and are shown in Tables 4 and 5. Before these tables and all subsequent tables can be discussed, it is necessary to determine whether the values obtained for the plats 4 and 5 rows wide can be compared with those obtained for other widths. The values are considered to be comparative in this and in all future tables because similar calculations from 1-, 2-, and 3-row plats for the areas of 80 and 75 rows in width, respectively, are in close agreement with those calculated for the entire area of 90 rows. These values are also shown in Tables 4 and 5.

Considering the entire plats, the standard error in percentage of the mean decreases as the length of the plat is increased, the greatest reductions occurring when the plats are increased from 10 to 20 feet in length. Considerable further reduction in percentage error occurs when the plats are increased to 30 feet in length, but, when the length

TABLE 3.—*Yield of beans in grams from 1,890 single-row plats each 10 feet long.*

Plat No.	Series No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	361	334	343	373	433	468	365	467	430	446	474	470	384	438	407	312	304	390	370	382	370
2	353	465	502	376	500	468	387	490	600	347	488	482	510	425	435	435	438	425	602	557	531
3	330	340	416	438	450	527	333	485	530	450	538	605	487	440	410	440	386	433	516	430	582
4	381	398	540	430	520	417	467	481	533	511	470	590	555	418	614	570	270	348	470	467	600
5	418	225	538	430	450	480	490	530	465	505	473	602	545	485	520	415	416	440	360	515	540
6	412	405	455	443	498	438	381	480	462	404	520	550	626	433	516	320	413	381	425	315	465
7	370	367	476	470	470	520	440	456	440	545	585	562	670	478	516	495	417	460	435	460	430
8	305	351	605	435	465	556	465	440	557	457	504	586	491	460	551	395	295	528	457	420	502
9	373	425	518	484	535	488	440	506	590	415	438	510	542	425	431	465	410	475	435	560	550
10	334	387	613	490	575	532	472	530	490	482	432	444	490	424	528	450	425	402	482	446	488
11	385	400	619	564	550	480	480	481	519	376	480	498	460	405	525	453	455	475	461	557	530
12	390	415	590	567	617	612	430	465	415	432	535	522	432	421	535	437	486	448	483	509	485
13	381	378	565	488	588	457	492	486	450	364	554	426	410	420	485	468	419	423	575	570	550
14	456	482	546	482	535	500	450	471	485	477	523	494	512	431	600	535	462	536	552	560	556
15	420	495	475	448	593	406	516	445	470	370	408	554	445	440	440	364	488	530	445	565	525
16	390	473	445	521	479	470	458	515	380	443	565	360	378	460	575	560	323	490	470	470	405
17	402	495	570	455	498	520	518	570	540	432	519	494	414	441	450	415	470	498	495	630	523
18	388	507	431	562	476	432	480	359	515	334	424	524	449	426	548	456	496	437	490	480	415
19	362	523	448	455	478	500	474	425	478	464	474	488	381	400	562	495	307	400	410	435	366
20	360	470	512	457	466	598	443	470	385	464	420	533	480	515	476	558	456	442	535	640	455
21	405	598	441	425	495	437	579	474	432	389	410	431	375	470	545	360	555	518	505	525	445
22	339	483	452	450	465	420	500	505	512	490	540	400	390	360	475	468	450	480	418	440	462
23	398	470	406	452	468	583	507	572	420	526	460	458	473	385	618	474	507	472	525	530	458
24	287	443	451	444	389	612	508	424	573	515	505	394	338	438	577	485	512	550	517	463	400
25	517	445	458	450	530	561	494	585	492	504	486	410	463	448	656	446	620	560	405	385	400
26	467	472	440	510	540	525	484	555	545	475	505	400	374	354	634	488	490	450	557	452	445
27	386	492	449	506	495	512	495	474	645	399	457	399	462	480	425	591	390	490	454	512	400
28	475	445	410	560	450	565	490	556	509	453	513	445	485	520	521	605	485	545	512	415	370
29	450	455	460	519	537	504	425	540	505	534	483	430	505	474	535	612	304	473	376	447	380
30	404	412	412	393	414	540	452	481	460	470	430	460	479	473	621	530	498	506	400	410	414
31	475	435	458	586	525	520	453	500	482	685	430	485	525	450	500	550	485	515	438	497	462

32	392	431	410	572	568	583	530	520	470	625	606	485	505	422	465	565	497	439	445	443	380
33	394	455	412	256	440	535	505	458	570	603	438	465	435	417	512	544	476	480	454	377	444
34	396	440	385	508	660	515	415	521	475	547	555	456	453	380	640	470	435	494	350	365	435
35	390	425	355	420	610	405	558	465	560	556	510	540	419	455	538	520	570	457	470	360	450
36	385	445	340	455	560	510	516	484	505	451	596	475	438	393	430	430	465	430	375	407	417
37	352	360	395	519	548	557	587	600	485	486	505	532	365	455	654	488	488	495	494	396	420
38	388	425	335	414	645	625	518	620	605	475	507	564	638	495	545	590	544	521	562	384	430
39	368	440	410	448	580	600	500	568	390	480	440	608	402	415	517	481	437	563	525	400	403
40	387	485	420	558	575	460	478	492	478	555	445	588	458	405	575	555	690	597	550	495	334
41	336	446	380	488	545	540	645	414	570	472	440	560	557	476	596	590	662	557	562	456	455
42	324	465	421	390	596	630	507	419	390	535	486	457	352	376	572	600	555	468	575	420	452
43	423	392	408	482	490	620	492	450	555	476	468	550	385	334	426	557	615	556	507	405	368
44	370	490	447	460	645	577	626	445	682	470	526	584	377	432	605	532	466	455	385	364	344
45	388	413	418	535	609	492	530	362	586	479	530	466	395	640	615	507	458	505	580	430	336
46	350	608	390	355	410	565	462	305	605	550	534	385	386	472	445	490	372	402	505	557	320
47	348	452	405	587	565	475	546	390	555	487	330	345	373	430	545	505	400	470	447	385	365
48	330	404	325	468	507	660	463	360	440	392	417	465	383	429	502	437	342	420	458	302	437
49	417	386	402	421	614	566	548	350	485	556	450	380	460	400	530	560	425	555	440	371	396
50	510	405	360	550	570	703	375	345	485	580	468	446	402	412	530	515	462	425	360	357	385
51	405	345	370	495	541	567	470	320	382	513	474	503	483	410	563	340	426	446	420	320	298
52	265	411	414	392	548	505	450	420	424	450	415	498	385	466	532	410	324	437	370	350	300
53	461	394	355	510	455	545	410	437	368	445	500	427	435	351	512	466	348	393	356	425	300
54	340	392	315	446	520	391	531	315	440	392	516	360	318	290	448	402	401	385	420	354	328
55	348	445	370	343	580	470	451	343	400	395	395	435	370	318	444	412	305	390	439	366	386
56	364	420	318	422	520	453	487	390	534	410	490	400	419	217	434	375	286	378	395	370	260
57	335	335	314	332	578	437	468	370	435	388	434	450	373	345	415	419	270	303	350	365	315
58	353	392	350	432	500	461	425	425	475	353	365	352	448	366	430	415	387	375	393	500	422
59	375	367	350	405	484	418	384	400	435	384	377	354	265	355	541	450	250	310	377	431	392
60	295	296	377	300	335	430	375	392	473	389	344	440	340	386	455	350	260	373	393	480	440
61	302	330	285	267	434	437	344	365	373	373	306	332	367	290	420	335	240	312	420	400	465
62	252	330	404	570	400	410	345	375	377	411	395	422	325	407	508	430	345	383	613	487	420
63	372	390	394	555	565	400	405	458	368	338	466	442	350	403	440	445	357	354	540	483	350
64	310	450	380	448	340	455	462	335	466	360	334	314	405	481	452	358	374	358	450	362	365
65	341	320	388	490	448	440	399	435	455	364	332	420	365	392	470	426	338	434	426	555	300
66	287	268	425	485	480	444	370	466	590	435	292	332	334	384	405	428	380	436	442	355	352
67	368	332	382	490	456	545	444	567	390	474	358	400	388	344	446	427	274	325	312	386	356
68	310	337	406	524	475	510	560	530	540	522	335	425	517	463	387	415	410	335	340	310	475
69	300	325	358	475	515	432	382	490	458	440	356	440	436	430	455	392	352	226	310	352	453

TABLE 3.—*Concluded.*

Plot No.	Series No.																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
70	352	354	325	540	405	478	429	420	465	345	425	415	555	503	415	440	410	373	290	400	470
71	375	354	388	482	555	426	468	506	465	418	345	571	437	420	485	430	376	228	260	398	492
72	306	320	432	417	475	512	475	440	436	500	456	438	516	445	564	534	348	337	329	365	555
73	375	387	242	390	458	431	363	455	438	520	509	551	494	485	660	407	404	329	331	487	406
74	355	365	444	348	440	483	419	377	460	530	490	460	525	552	540	473	455	367	294	409	523
75	345	425	395	370	436	556	515	492	525	511	571	523	454	467	575	435	441	319	340	345	531
76	370	420	415	371	377	425	481	415	473	420	595	511	510	509	416	492	468	370	339	385	534
77	414	366	325	400	401	367	416	370	550	425	485	413	515	454	570	470	331	451	374	258	528
78	316	287	311	312	305	364	431	407	483	509	404	408	550	444	525	420	400	372	275	380	464
79	289	286	376	345	400	452	392	366	540	380	533	355	407	452	458	460	485	335	270	276	385
80	335	336	343	325	375	442	351	338	475	533	460	425	435	470	512	490	565	316	528	456	435
81	395	335	336	424	365	532	420	432	520	485	467	388	400	430	610	440	405	408	398	355	428
82	323	394	355	420	405	450	458	443	625	570	548	475	450	375	515	490	490	414	475	350	395
83	400	380	280	460	473	450	530	370	498	565	435	510	405	362	586	500	395	331	371	380	390
84	370	410	260	402	470	525	456	292	565	524	451	435	339	386	610	548	410	412	483	405	290
85	354	390	246	415	534	473	568	475	473	440	390	440	408	468	590	495	365	329	452	404	295
86	365	406	380	344	435	505	449	510	525	438	453	432	485	505	603	532	450	400	375	365	450
87	350	357	357	320	435	573	520	460	562	393	414	439	452	543	635	530	402	376	334	410	475
88	300	278	325	350	375	495	470	545	543	509	451	524	583	462	645	520	445	427	440	350	465
89	335	256	348	381	468	474	542	492	445	470	464	495	498	562	627	452	376	420	392	396	407
90	387	314	340	395	352	506	574	438	485	330	416	400	387	413	430	480	540	548	535	427	372

TABLE 4.—*Standard errors of single plats in percentage of the mean of yields of plats varying in size and shape when entire plat was used.*

Length of plat, feet	No. of series of plats used end to end across the field	Width of plats in rows							
		1	2	3	4	5	6	9	18
10	21	90* 12.67	45 9.98	30 9.74			15 10.30	10 9.25	5 9.83
		80 12.94	40 10.03		20 10.18				
		75 12.88		25 9.73		15 8.15			
10	20	90 12.11	45 9.93	30 9.71			15 10.25	10 9.13	5 9.75
		80 12.27	40 9.99		20 10.23				
		75 12.25		25 9.73		15 8.93			
20	10	90 9.38	45 7.83	30 8.03			15 9.09	10 7.94	5 8.99
		80 9.43	40 7.82		20 8.73				
		75 9.36		25 7.99		15 7.45			
30	7	90 7.89	45 6.60	30 6.90			15 8.14	10 7.07	5 8.48
		80 7.96	40 6.72		20 7.94				
		75 7.90		25 7.04		15 6.22			
40	5	90 7.28	45 6.51	30 6.63			15 7.75	10 6.18	5 7.92
		80 7.23	40 6.24		20 7.47				
		75 7.20		25 6.62		15 5.72			
50	4	90 6.72	45 5.66	30 6.25			15 7.59	10 6.12	5 7.91
		80 6.78	40 5.81		20 7.20				
		75 6.74		25 6.44		15 5.53			

*The small figures in each compartment indicate the number of plats side to side across the field.

TABLE 5.—*Standard errors of single plats in percentage of the mean of yields of plats varying in size and shape when border rows were removed.*

Length of plat, feet	No. of series of plats used end to end across the field	Width of plat in rows				
		3, 1 row used	4, 2 rows used	5, 3 rows used	6, 4 rows used	9, 7 rows used
10	21	30* 13.40 25 13.42	20 12.09	15 9.93	15 11.12	10 10.06
10	20	30 13.42 25 13.46	20 12.09	15 9.81	15 11.01	10 9.97
20	10	30 10.26 25 10.34	20 9.84	15 8.00	15 9.47	10 8.59
30	7	30 8.67 25 8.77	20 8.72	15 6.63	15 8.36	10 7.61
40	5	30 8.06 25 8.01	20 7.73	15 6.33	15 8.11	10 6.64
50	4	30 7.36 25 7.44	20 7.72	15 6.01	15 7.77	10 6.47

*The small figures in each compartment indicate the number of plats side to side across the field.

of the plat is increased to 40 or 50 feet, further reduction does not compensate for the increase in land used, as is shown in Table 6.

Increasing the width of the plat from 1 row to 2 rows shows a great reduction in percentage error, comparable to increasing the length from 10 to 20 feet. Increasing the width of plats to 3 rows reduces the percentage error slightly while further increases in width change the results but very little.

When the border rows are discarded and only the center rows used in the calculations, the results are similar to those obtained when the entire plat is used. A great reduction in percentage error was noted when the length of plat was increased from 10 to 20 feet and a still further reduction noted when the length was increased to 30 feet, but very little difference was noted beyond that point. Increasing the width of the plat from 3 rows to 4 rows resulted in a slight decrease in the percentage error, but when the width was increased to 5 rows a considerable reduction was observed. Increasing the width of the plat to 6 and 9 rows showed very little change one way or the other. The standard error was in all but one case greater than when all the rows of the same-sized plats were used in the calculations. Increasing the size of plats to allow for the discarding of the border rows resulted in some increase in the percentage of the standard error in all but three cases where a corresponding number of rows were harvested. This means that there was greater variability be-

TABLE 6.—*Theoretical number of replications needed to reduce the standard error of the mean to 4% when the entire plat was used.*

Length of plat, feet	No. of series of plats used end to end across the field	Width of plats in rows							
		1	2	3	4	5	6	9	18
		10.0	6.2	5.9	—		6.6	5.3	6.0
		10.5	6.3		6.5				
10	21	10.4		5.9		4.2			
		9.2	6.2	5.9			6.6	5.2	5.9
10	20	9.5	6.2		6.5				
		9.4		5.9		5.0			
		5.5	3.8	4.0			5.2	3.9	5.0
20	10	5.6	3.8		4.8				
		5.5		4.0		3.5			
		3.9	2.7	3.0			4.1	3.1	4.5
30	7	3.9	2.8		3.9				
		3.9		3.1		2.4			
		3.3	2.6	2.7			3.8	2.4	3.9
40	5	3.3	2.4		3.5				
		3.2		2.7		2.0			
		2.8	2.0	2.4			3.6	2.3	3.9
50	4	2.9	2.1		3.2				
		2.8		2.6		1.9			

tween the plats of a block when only the center rows were harvested than when the entire plat of the same number of harvested rows was used.

NUMBER OF REPLICATIONS

The theoretical number of replications required by any given size of plat to reduce to 4% the standard error of the mean of that number of replications may be obtained by dividing the standard error percentages, as given in Tables 4 and 5, by 4 and squaring these quotients. The values thus obtained are given in Tables 6 and 7. The value of 4% was chosen because normally this is the approximate size of the standard error of nine replications of beans at the Michigan Station.

The theoretical number of replications for the entire plat tended to decrease as the length of the plat was increased. The greatest difference in number was observed when the plat was increased from 10 to 20 feet, the number of replications for the 20-foot plats being nearly one-half of that for the 10-foot plats in the two narrowest widths. There was a further noticeable decrease when the length of the plat was increased from 20 to 30 feet but scarcely any when increased beyond that.

When the width of the plat was increased from 1 row to 2 rows, there was also a decided decrease in the number of replications required, but further increase in the number of rows per plat made very little change in the theoretical number of replications necessary to reduce the standard error of the mean to 4%.

TABLE 7.—*Theoretical number of replications needed to reduce the standard error of the mean to 4% when the border rows were removed.*

Length of plat, feet	No. of series of plats used end to end across the field	Width of plat in rows				
		3, 1 row used	4, 2 rows used	5, 3 rows used	6, 4 rows used	9, 7 rows used
10	21	11.2 11.3	9.1	6.2	7.7	6.3
10	20	11.2 11.3	9.1	6.0	7.6	6.2
20	10	6.6 6.7	6.0	4.0	5.6	4.6
30	7	4.7 4.8	4.8	2.7	4.4	3.6
40	5	4.0 4.0	3.7	2.5	4.1	2.8
50	4	3.4 3.4	3.7	2 3	3.8	2.6

Practically the same thing was true when the border rows were discarded and only the center rows used in the calculations. The greatest decrease was noted in the 3-row plats when the length of the plat was increased from 10 to 20 feet. Increasing the length of the plats to 30 feet tended to reduce the number still more, but when increased to 40 and 50 feet the reduction in theoretical number of replications was small.

When the two center rows of the 4-row plats or the three center rows of the 5-row plats were used instead of the center one of the 3-row plats, the theoretical number of replications was appreciably decreased, but a further increase in number of rows to 6 and 9 did not reduce the number greatly.

COMPARATIVE LAND EFFICIENCY

Tables 6 and 7 indicate that as the plat was increased in length and, to some extent, in width, the number of replications needed to put the standard error to the common basis of 4% of its mean was reduced. However, the larger plats required more land. To determine, then, which size and shape of plat used the land most effectively, the comparative land efficiency values for the 108 sizes and shapes of plats were obtained. It was assumed that a plat 10 feet long and 1 row wide had an efficiency of 100%. According to Table 6, a plat 10 feet long and 2 rows wide required 6.2 replications to reduce the standard error of the mean to 4%. Since the plat was 2 rows wide,

6.2 was multiplied by 2 and this product divided into 10.0 (the theoretical number of replications needed for a plat 10 feet long and 1 row wide) times 100 to give per cent. Thus, $\frac{10.0 \times 100}{6.2 \times 2} = 80.5\%$. Values for land efficiency calculated in this way are given in Tables 8 and 9.

TABLE 8.—*Percentage efficiency in use of land of plats varying in size and shape when entire plat was used.*

Length of plat, feet	No. of series of plats used end to end across the field	Width of plat in rows							
		1	2	3	4	5	6	9	18
		100.0	80.5	56.4			25.2	20.8	9.2
10	21	100.0	83.2		40.4				
		100.0		58.4		49.9			
		100.0	74.4	51.8			23.2	19.5	8.6
10	20	100.0	75.4		36.0				
		100.0		52.8		37.7			
		83.4	59.7	37.8			14.8	12.9	5.0
20	10	84.6	61.5		24.7				
		85 7		39.2		27.1			
		85.9	61.4	37.4			13.4	11.9	4.1
30	7	88.1	61.9		22.2				
		88.7		37.2		28.9			
		69.1	43.3	27.8			10.2	10.6	3.2
40	5	71.9	48.3		16.8				
		72.4		28.5		22.9			
		64.8	45.8	25.0			8.5	8.7	2.6
50	4	65.5	44.6		14.5				
		66.2		24.1		19.6			

It will be noted in Table 8 that when the length of the plat was increased from 10 to 20 feet the percentage of land efficiency was materially decreased, but when the length of the plat was increased from 20 to 30 feet, the land efficiency percentage value did not decrease. When the length of plat was increased still further, there was a considerable decrease in the percentage of land efficiency. An increase in the number of rows per plat from 1 to 2 caused a decrease in the percentage of land efficiency. Still further decreases in land efficiency were noted when the number of rows per plat was increased to 3, to 5, and so on to 18.

In Table 9 are given the comparative land efficiency values for the plats when the border rows were discarded and only the center rows were used. As in Table 8, the shorter plats were the more efficient ones. Unlike the results from the entire plats, it is seen that the land efficiency values for the three center rows of the 5 row plats 10, 20, and 30 feet long were slightly higher than the efficiency values for the center rows of plats 3 and 4 rows wide of similar length.

TABLE 9.—*Percentage efficiency in use of land of plats varying in size and shape when the border rows were removed.*

Length of plat, feet	No. of series of plats used end to end across the field	Width of plat in rows				
		3, 1 row used	4, 2 rows used	5, 3 rows used	6, 4 rows used	9, 7 rows used
		29.8			21.6	17.6
10	21		28.6			
		30.7		33.6		
		27.3			20.2	16.4
10	20		25.7			
		27.6		31.2		
		23.2			13.6	11.0
20	10		19.4			
		23.4		23.5		
		23.7			12.7	10.3
30	7		18.3			
		23.9		25.1		
		18.8			9.3	9.2
40	5		15.2			
		19.5		18.7		
		18.0			8.1	7.8
50	4		12.6			
		18.1		16.6		

A comparison of Tables 8 and 9 shows that harvesting the entire plat is more efficient than using only part of the plat, and that the difference in efficiency is much greater in the narrower widths of plat.

SUMMARY

Summarizing the results which have been obtained it can be said that for this field of beans:

The standard errors in percentage of their respective means were greater in nearly all cases when only the center rows of a plat were used than when the entire plat was harvested. This was true whether the comparison was between equal numbers of rows harvested or equal numbers of rows per plat.

The standard error in percentage decreased as the area of the plat increased, except as noted in the preceding paragraph. The decreases were consistent with increases in length, but were not entirely consistent with increases in width.

Rather large decreases in magnitude of percentage standard error occurred when the plat length was increased from 10 to 20 and on to 30 feet. Comparatively small decreases were found when the plat length was increased beyond 30 feet.

Rather large decreases in magnitude of percentage standard errors were observed as the plat width was increased to 2 rows, but variable results were obtained as the plat width was increased beyond 2 rows.

On the whole, increasing the size of the plat by increasing its length

proved much more effective in reducing the standard error in percentage of its mean than making a similar increase in plat size by increases in width.

The number of replications needed to reduce the standard errors to the same comparable basis of 4% followed the same trends as did the standard errors. This is not to be wondered at as the number of replications was dependent on the magnitude of the standard error.

An increase in the theoretical number of replications decreases the standard error more rapidly than an equivalent increase in the size of plat. This is especially true when the plat is increased in width.

The comparative land efficiency values bring out more strongly than the standard errors alone the greater desirability of harvesting entire plats in comparison to harvesting only the center rows of the plat.

When the entire plat was harvested, plats one row wide and 30 feet long were slightly more efficient than plats the same width 20 feet long, and much more efficient than plats two rows wide and only 10 feet long.

Although the comparative land efficiency values indicate that the 10-foot, 1-row plats were the most efficient in the use of land, yet there are several other factors not considered under standard error and land efficiency values which must be considered. These are ease of planting, of harvesting, of threshing, and of subsequent laboratory determinations.

Planting four replications (Table 6) of plats 30 feet long and 1 row wide is much easier, consumes less time, and is subject to fewer mistakes than planting 10 replications of plats 10 feet long and 1 row wide.

CONCLUSIONS

The data obtained from 1,890 10-foot plats of white pea beans studied by the variance method indicate that plats 30 feet long and 1 row wide replicated four times were more efficient in the use of land for the reducing of the standard error in percentage of its mean than all the other 107 shapes and sizes studied, except the original ultimate units 10 feet long and 1 row wide.

Field operations, such as planting, harvesting, threshing, and subsequent laboratory determinations, indicate that the use of plats 30 feet long and 1 row wide which requires but four replications is more desirable than that of the more land-efficient but smaller plats 10 feet long and 1 row wide, which requires 10 replications.

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THE COMPARATIVE EFFICIENCY OF FREE AND COMBINED NITROGEN FOR THE NUTRITION OF THE SOYBEAN[1]

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RECENT agronomic studies on pasture mixtures supplied various fertilizers indicate that leguminous plants are apparently unable to compete successfully with nonleguminous crops in the presence of an adequate supply of fixed available nitrogen. This fact might be interpreted to mean that the products of symbiotic nitrogen fixation are better suited for the development of leguminous plants than are the products elaborated from combined sources. On the other hand, it is well established that a supply of fixed nitrogen reduces nodule formation and nitrogen fixation which suggests that leguminous plants may prefer combined nitrogen and only resort to the process of fixation when there is no fixed nitrogen available. The question is thus raised, "Is free or combined nitrogen the better source of nitrogen for leguminous plants?"

Results from experiments carried out at the Wisconsin Agricultural Experiment Station during the past three summers indicate that the answer, in the case of the soybean plant at least, is a function of the carbohydrate-nitrogen relation in the plant. This relation may be varied in a number of ways, e. g., an unfavorable pH may at one time be the cause of a low carbohydrate-nitrogen relation, while low light intensity or low temperature may, at another time, be the cause of a similar relation; but independent of the method of change, a given type of plant with reference to its carbohydrate-nitrogen relation will give a definite response to the form of nitrogen supplied.

EXPERIMENTAL PROCEDURE

Three series of Manchu soybeans were used in each experiment as follows:

1. *Inoculated.*—Plants were inoculated with a mixture of Wisconsin strains 9, 17, and 505 of *Rh. japonicum*, but no forms of combined nitrogen were added. Nodule development was that characteristic of a good strain.

2. *High nitrogen.*—Plants were not inoculated, but fixed forms of nitrogen were added in excess. In the data to be discussed the fixed nitrogen was added as ammonium nitrate. In similar experiments in the previous summer, calcium nitrate was used with essentially the same results, but since the range of observation was more limited and the data incomplete it has been omitted in this consideration. In all cases the plants were periodically supplied with all the nitrogen they could assimilate—equivalent to 150 to 200 pounds per acre, or even more in some cases. No nodules were present.

3. *Low nitrogen.*—Plants were not inoculated but furnished with ammonium nitrate in a quantity more comparable to that used in actual practice—75 to

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100 pounds per acre. Except in the case indicated (experiment II), the amount added was exactly half that given the high-nitrogen series. No nodules were present.

Representative pots were first harvested when the plants were about a month old, and harvests were made at approximately weekly intervals until the plants were mature. The first harvest corresponded to the time when fixation of nitrogen began in the inoculated series. The details of the methods of plant culture, harvesting, and analysis are essentially those described by Orcutt and Fred (7).[3]

Analysis of the data obtained from plants having different types of carbohydrate-nitrogen relation shows that four distinct situations obtain. These may be conveniently summarized as follows:

Case I.—The first case is that of excessive carbohydrate synthesis. Under these circumstances inoculated plants fail to come out of the nitrogen-hunger period, while plants supplied combined nitrogen develop normally. This case has been reported by Orcutt and Fred (7) who suggested that the inhibition of the inoculated plants arose primarily from excessive carbohydrate. Wilson (11) has shown that the results of Rüffer (8) and Hopkins (4) lend themselves readily to a similar interpretation. It is concluded that, *if an excessive carbohydrate-nitrogen relation develops in the plants, the growth is favored by the presence of combined nitrogen.*

Case II.—The second case considered is that in which a balanced carbohydrate-nitrogen relation exists within the plant. This normally occurs under adequate sunlight of moderate intensity and in the presence of sufficient moisture and carbon dioxide. An experiment giving plants of this type was conducted in the summer of 1935. In Fig. 1 are shown plants (seeded May 17, 1935) after approximately 2 months of growth. All the plants showed excellent growth, although those inoculated are considerably ahead of the others. The superiority of the inoculated plants continued throughout the entire growth period and was particularly striking at maturity.

Data from the different harvests (Fig. 4A) show that the dry weights per plant of the three series were approximately the same for almost 2 months, after which the plants of the inoculated series show a greater rate of increase than the plants of the combined nitrogen series, and at the final harvest are distinctly superior. On the basis of milligrams of nitrogen per plant, the plants of the inoculated series were richer in nitrogen throughout their entire growth period. It is emphasized that an adequate level of combined nitrogen was present in the substrate of the high combined nitrogen series at all times. It therefore appears that during maturation the plants of the inoculated series (using free nitrogen) continue to assimilate the elemental form, but assimilation of combined nitrogen does not occur as readily.

Inasmuch as it is difficult to control the growth of a series of plants so that at a given time they will all be excatly at the same state, i. e., have the same dry weight or total nitrogen, a better criterion for the effects of any factor affecting development might be *rate of growth* rather than total yields since growth rates are essentially independent of the initial state. Growth rates were calculated for each experiment

[3]Figures in parenthesis refer to "Literature Cited", p. 555.

discussed in this report, and these gave the same conclusions as are drawn from the total yield data.

The data of this experiment show that *under conditions which give an optimumly balanced carbohydrate-nitrogen relation within the plant, free nitrogen is more readily assimilated than is ammonium nitrate.*

Case III.—The third case considered is that in which the carbohydrate-nitrogen relation in the plants is somewhat less optimum

High Nitrogen Inoculated

FIG. 1.—Experiment I, optimum carbohydrate-nitrogen relation.

than in plants of the previous series. Such a condition would result when any of the growth factors were somewhat sub-optimum. An experiment in which this type of growth was obtained was seeded June 17, 1935. Since this represents a rather late planting for Wisconsin climate, the environmental conditions are not optimum for maximum growth. The photograph in Fig. 2 shows plants of the high combined nitrogen and inoculated series after approximately 2 months of growth. At this time the plants of the inoculated series were definitely superior, although over the earlier period they were closely parallel (Fig. 4B). The slight lag in the curve of dry weight for the plants of the inoculated series is possibly due to the carbohydrate energy required for fixation. Note that with respect to the accumulation of nitrogen, the plants of the inoculated series were slightly behind the others during the earlier periods of growth, but as development proceeds, they forge ahead of the plants supplied combined nitrogen. As was noted in the first experiment, the plants of the combined nitrogen series on approaching maturity do not as

readily absorb nitrogen from the adequate level present in the substrate as the plants of the inoculated series assimilate free nitrogen.

Thus, it appears that even *under conditions in which the carbohydrate-nitrogen relations in the plant are somewhat sub-optimum, inoculated soybeans developed better than soybeans given ammonium nitrate,* largely because of lack of assimilation of the combined nitrogen during the period of maturation.

High Nitrogen Inoculated

FIG. 2.—Experiment II, near-optimum carbohydrate-nitrogen relation.

Case IV.—The final case considered is that of deficient carbohydrate synthesis. If the production of carbohydrate falls to a point where there is a distinct lack of this supply of energy, one finds greater plant development in those cultures receiving fixed nitrogen; the most normal development is observed in the cultures having just sufficient combined nitrogen to unite with the low supply of carbohydrate available.

Soybean plants representative of this case are produced by very late seeding. The environmental conditions (shorter days, less intense light, lower temperatures) discourage photosynthetic activity and carbohydrate becomes the limiting factor in development. The photograph in Fig. 3 shows plants seeded August 15, 1935, after 2 months of growth under conditions producing an extremely narrow

carbohydrate-nitrogen relation within the plant. The plants receiving combined nitrogen are definitely superior, although growth of all is limited. Abnormalities of nitrogen "toxicity", such as leaf curling, were observed on the plants of the high combined nitrogen series. The curves for dry weight formation and nitrogen assimilation are given in Fig. 4C from which the superiority of the combined nitrogen is apparent. It should be observed that the plants of the high com-

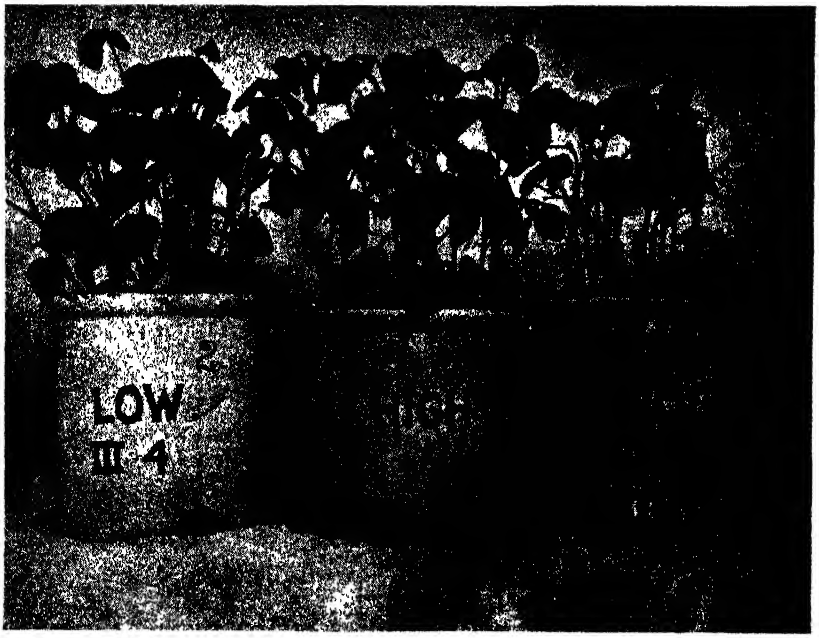

FIG. 3.—Experiment III, deficient carbohydrate.

bined nitrogen series were being pushed beyond normal healthy development; soluble nitrogen in plants of this series was excessively high in amide. Data of this experiment suggest that the energy required for the assimilation of combined nitrogen is definitely lower than that for uptake of free nitrogen, since even with a low level of carbohydrate energy available, not only did the plants absorb excessive combined nitrogen, but also show definite increases in dry weight over the plants in the inoculated series.

The data of this experiment show that *under conditions in which carbohydrate synthesis is restricted, the best development of soybeans is obtained in those plants which are furnished combined nitrogen.*

DISCUSSION

These experiments point out that in inoculated soybean plants grown under conditions which produce a balanced carbohydrate-nitrogen relation within the plant, the products of symbiotic nitrogen fixation appear better suited for plant development than are those

elaborated from inorganic sources. This superiority of the elemental form as a nitrogen source is especially noticeable during the period of maturation. Whereas fixed nitrogen appears to be only slightly absorbed during this period, free nitrogen is readily assimilated. The experiments also show that if the environmental conditions are such that a plant with an unbalanced carbohydrate-nitrogen relation results, soybean plants develop better if fixed nitrogen, e. g., ammonium nitrate, is supplied.

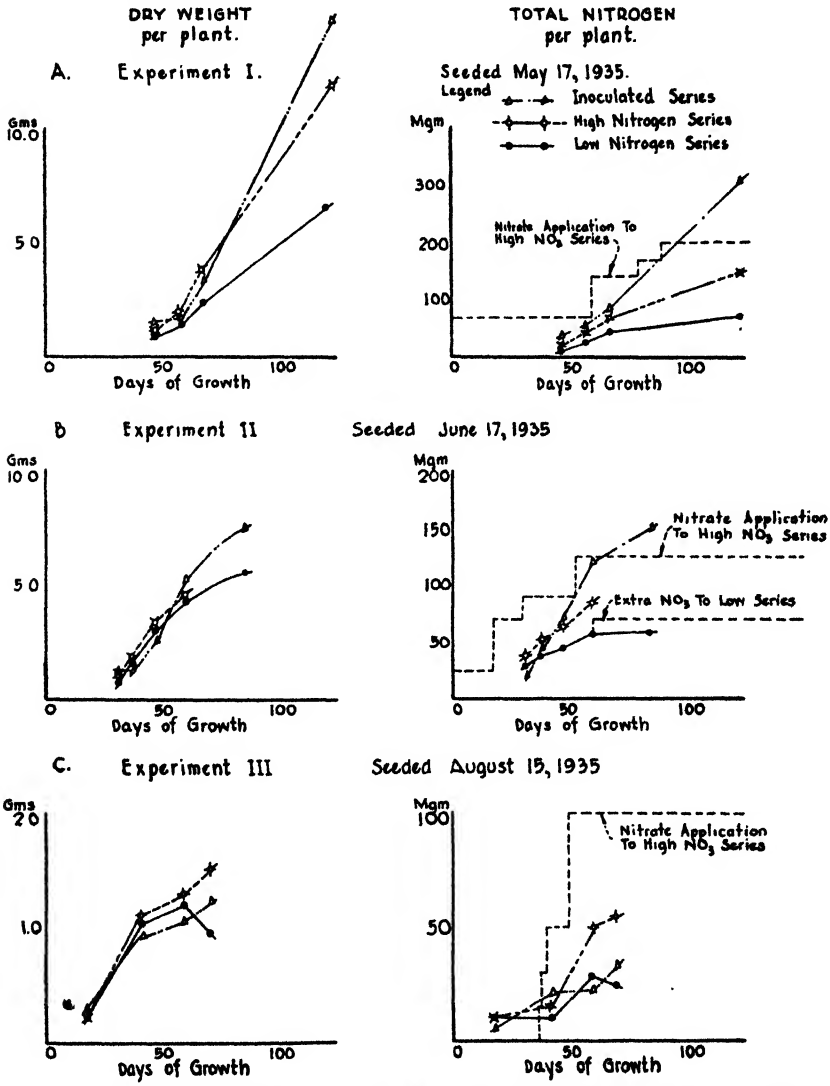

FIG. 4.—Effect of carbohydrate-nitrogen relation on dry weight and total nitrogen. A, optimum carbohydrate-nitrogen; relation B, near optimum carbohydrate-nitrogen relation; and C, deficient carbohydrate.

The cause of this difference in nutritive value of free and combined nitrogen cannot be definitely stated but two hypotheses, already in the literature, may be concerned. The first of these states that the better growth of inoculated leguminous plants under conditions of a relatively balanced carbohydrate-nitrogen relation is due to substances other than nitrogen which the bacteria contribute to the symbiotic relationship. Fred, Baldwin, and McCoy (1) have discussed the literature prior to 1931 dealing with the possibility that the symbiotic relationship might involve these "accessory growth factors". Since that time several reports (2, 3, 10) concerned with the stimulatory effect of vitamins in plant nutrition have appeared. Recently, McBurney, Bollen, and Williams (6) have shown that minute amounts of pantothenic acid stimulate the growth of alfalfa, although it does not influence the fixation process. However, actual proof that the bacteria *in the nodule* synthesize and excrete these growth substances for plant use is still lacking.

The second hypothesis maintains that the better growth of the inoculated leguminous plants in comparison with those supplied combined nitrogen is evidence that the *nitrogenous* products of fixation are better suited for development of these plants than are inorganic sources of combined nitrogen. The literature on the subject of preference of plants for different types of nitrogen compounds is enormous. It is sufficient to state here that plants do exhibit a preferential absorption of different types of combined nitrogen and have been observed to develop better on some forms than on others. Further, the best type of combined nitrogen is not necessarily inorganic, since in many cases organic nitrogen has been shown to produce maximum growth. Virtanen (9), for example, reports that red clover in sterile sand cultures was able to grow better on hydrolysed casein or aspartic acid than on inorganic nitrogen. Hopkins and Fred (5) report similar results with asparagine and yeast water.

SUMMARY

Soybeans have been grown under a variety of conditions which modify the carbohydrate-nitrogen relation of the plants. It is shown that the preferential form of nitrogen for the nutrition of these plants changes with the available carbohydrate present. Four distinct situations are discussed, *viz.*, case I, excessive carbohydrate; case II, optimum carbohydrate-nitrogen relation; case III, near-optimum carbohydrate-nitrogen relation; and case IV, deficient carbohydrate.

From the data presented it is concluded that:

1. Under conditions which result in a balanced carbohydrate-nitrogen relation in the soybean plant, free nitrogen is the preferred form of nitrogen nutrition.

2. Under conditions which result in an unbalanced carbohydrate-nitrogen relation in the plant, fixed nitrogen is desirable, since this may enable plants to survive an unfavorable environment.

3. Since the environmental conditions which produce plants with an unbalanced carbohydrate-nitrogen relation (high light intensity, drought, high CO_2, or low light intensity, low temperature, short days) are the exception rather than the rule, it is probable that under

field conditions maximum yields would be obtained with inoculated soybean plants rather than with those dependent on fixed forms of nitrogen for their nutrition. Nevertheless, certain climatic or field conditions are occasionally encountered which produce a plant with an unbalanced (excessive or deficient) carbohydrate-nitrogen relation and the use of combined forms of nitrogen would accordingly be indicated.

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UNIT OF QUANTITATIVE STUDY OF WEED FLORA ON ARABLE LANDS[1]

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OF late, the size and the form of unit that should yield a correct estimate of the nature of dispersion of species in quantitative ecology has been subjected to critical analysis by various schools of ecologists. Until now, however, little attention seems to have been directed toward studying the statistical nature of the distribution of weed flora on arable land. As such, the selection of the right form and size of unit which would give a correct estimate of the dispersion and density of the floral composition of the weeds on arable land becomes essential. In a uniform environment of the cultivated field, the factors of chance and random distribution are at their minimum, and as such, with the selection of a correct unit, a closer agreement may be brought about between the theoretical probability of distribution and the actual field data.

Arrhenius (1)[3] investigated the relation between the size of the quadrat and the average number of species found in the quadrat; but as is evident from his curves he obtained the relationship between the size of the quadrat and the average number of the species found in it by taking quadrats of a single size and form only, though in a large number, and subsequently grouping the random quadrats for the desired size. By this method he makes a theoretical assumption that there is a random distribution of the species which may be far from the reality of field data. To make up for the shortcomings of the above method, Gleason (3, 4) grouped the "contiguous" quadrats. But as the curves show, such a method also failed to give coherent results with the observed field data. Clapham (2), investigating the form of observational unit in quantitative ecology, claims that the strip form of unit is more efficient than the quadrat. His contention is that from the point-to-point variability of the floral composition, due to numerous causal factors such as soil heterogenity, the common gregarious and the rare solitary types of species, depending upon the probable chances of propagule dissemination, and the differences of the average area covered by the individual plants of different species, is minimized to a greater extent in a strip than in a quadrat. This assumption of the random distribution of species may be correct in the natural formation of vegetation, but it does not seem to be a correct assumption for the quantitative nature of weed species mosaic on arable land.

EXPERIMENTAL

During the investigations described here the quantitative nature of the weed flora on the arable land at the Benares Institute of Agricultural Research was determined, comparing the relative efficiency

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[3]Figures in parenthesis refer to "Literature Cited", p. 561.

of both units, namely, the quadrat and the strip, by the method of variance. For this purpose, a sample quadrat with sides of 5 meters was taken in an unploughed plat with a history of uniform crop production and left fallow during the winter of 1935. This area was divided by 1-mm wires and cross wires into 625 small squares each with a side of 1/5 meter. Seven counts were made in these small squares for *Cyprus rotundus*, *Euphorbia hirta*, *Tricodesma indica*, *Asphodelphous tennifolius*, *Sphaeranthus indica*, *Euphorbia dracenculoides*, and *Chenopodium album*, which were selected because of the ease of counting and on account of the variation in their density falling within certain limits.

The data thus collected have been analyzed for the strips running North and South, i. e., 25 × 1 small squares in that direction; for the strips running East and West compounded in the above manner; and for quadrats of 5 × 5 small squares. On the whole, the area for a single strip or a quadrat was the same, i. e., 1 square meter. The data analyzed in the above manner are represented in Table 1.

The efficiency of the strips and the quadrats is compared by the classical method (5) of estimating the variance for the total population as well as individual species by the formula $1/N - 1 \times S^n (x - \bar{x})^2$, where $N - 1$ represents the degrees of freedom and x and $\bar{x}$ represent the count and the mean of the counts made, respectively. In the above manner the variance for the individual species was also estimated for the quadrat as well as for the strip.

This statistical procedure gives three sets of figures, each set consisting of 25 counts for seven different species. For each, the sum of the squares of the deviation about the particular species' mean is calculated and the grand total divided by 168 (7×24 ($n - 1$)). So also, the sum of the squares of the deviation of the individual species mean was divided by 24 ($n - 1$) and gave the variance for the particular species. The density of each species (percentage composition of the particular species in the total vegetation) was calculated. The variances in the quadrats and the strips and density of species are represented in Table 2.

It is evident from the analysis of variance that the quadrats are far less variable in the ratio of 75:371, thus for the same area counted the accuracy of the estimate in the quadrats is 4½ times greater than that of the strips, but this efficiency of the quadrat is maintained till a particular level of density is reached.

As shown by curves 1 and 2 in Fig. 1, the quadrats are less variable where the species comprise over 20% of the total vegetation; but with the reduction of the density of the species, the variance is less in the strips. Thus, it is found that a species like *Tricodesma indica*, forming only 0.95% of the total vegetation, is significantly less variable in the strips than in the quadrats reaching an efficiency in the ratio of 1:4. Thereby, in the estimation of minor species below 5% density, the strips are less variable as shown by curves 3 and 4 (Fig. 1) indicating their efficiency in giving a more correct value.

The above observations point out the inefficiency of the strip form of unit which naturely involves the edge errors. Its efficiency is all the more lessened in the uniform environment of arable land where the

TABLE 1.—*Distribution of weed flora on arable land at the Benares Institute of Agricultural Research.**

																				Cr	Eh	Ti	At	Si	Ca	Ed
Cr	73	Ca	104	Cr	65	Ca	57	Cr	71	Ca	67	Cr	57	Ca	78	Cr	54	Ca	55	87	2	3	52	10	41	1
Eh	2	Ed	1	Eh	9	Ed	1	Eh	0	Ed	4	Eh	1	Ed	0	Eh	0	Ed	2	21	3	4	12	10	125	2
Ti	1			Ti	1			Ti	0			Ti	6			Ti	2			65	4	2	13	8	83	2
At	19			At	24			At	21			At	25			At	21			81	0	1	17	7	27	1
Si	17			Si	17			Si	7			Si	5			Si	8			66	3	0	16	4	80	2
Cr	67	Ca	82	Cr	37	Ca	64	Cr	30	Ca	71	Cr	42	Ca	60	Cr	60	Ca	53	25	4	3	62	8	136	2
Eh	1	Ed	4	Eh	7	Ed	1	Eh	4	Ed	2	Eh	2	Ed	3	Eh	0	Ed	1	34	3	2	21	7	38	3
Ti	7			Ti	0			Ti	4			Ti	0			Ti	0			93	2	1	14	9	24	1
At	28			At	37			At	35			At	42			At	36			24	3	2	52	6	93	2
Si	7			Si	9			Si	7			Si	14			Si	3			60	2	3	29	10	39	3
Cr	43	Ca	48	Cr	68	Ca	75	Cr	72	Ca	83	Cr	51	Ca	65	Cr	47	Ca	59	95	6	2	60	18	34	1
Eh	9	Ed	0	Eh	4	Ed	5	Eh	7	Ed	0	Eh	6	Ed	0	Eh	10	Ed	0	68	8	2	19	8	128	2
Ti	0			Ti	5			Ti	1			Ti	3			Ti	0			17	9	1	68	14	91	0
At	43			At	40			At	45			At	29			At	26			61	7	3	21	10	27	1
Si	12			Si	6			Si	13			Si	11			Si	10			40	6	1	15	2	50	1
Cr	59	Ca	56	Cr	64	Ca	79	Cr	29	Ca	102	Cr	41	Ca	93	Cr	44	Ca	72	79	5	0	55	8	146	1
Eh	3	Ed	0	Eh	3	Ed	1	Eh	2	Ed	2	Eh	8	Ed	0	Eh	6	Ed	1	34	8	0	15	10	38	0
Ti	0			Ti	0			Ti	0			Ti	2			Ti	0			85	4	1	12	5	112	1

At	46				At	23				At	33				At	39				At	41				25	3	1	61	7	86	2
Si	10				Si	9				Si	7				Si	2				Si	11				20	2	0	39	5	20	0
Cr	61	Ca	63		Cr	32	Ca	65		Cr	39	Ca	81		Cr	48	Ca	59		Cr	52	Ca	68		69	5	2	51	7	84	2
Eh	0	Ed	3		Eh	5	Ed	0		Eh	11	Ed	1		Eh	0	Ed	1		Eh	4	Ed	2		84	6	1	20	6	25	1
Ti	0				Ti	2				Ti	4				Ti	0				Ti	1				39	2	1	62	8	21	1
At	35				At	42				At	37				At	24				At	26				19	3	2	21	10	79	2
Si	14				Si	6				Si	4				Si	9				Si	8				21	4	1	10	10	23	1
28	84	39	81	71	79	37	51	42	57	69	25	74	31	42	89	41	27	71	11	57	29	21	61	81	Cr						
2	5	4	2	2	6	4	3	5	4	3	6	5	4	6	5	3	4	4	1	5	6	4	4	1	Eh						
1	2	1	2	2	2	3	1	0	2	2	3	1	2	1	3	2	2	1	3	1	0	0	1	1	Ti						
49	47	40	14	37	52	10	31	42	31	11	52	29	57	22	61	24	18	13	43	12	48	21	49	20	At						
13	8	16	7	6	8	10	6	4	4	12	6	7	8	5	11	8	9	5	8	7	9	12	5	7	Si						
44	108	113	23	15	88	132	12	69	39	25	129	89	77	82	141	24	36	98	56	114	22	73	24	34	Ed						
2	0	1	3	2	2	0	3	2	1	2	1	3	1	1	1	2	1	1	0	1	2	0	2	1	Ca						

*Cr = *Cyprus rotundus*; Eh = *Euphorbia hirta*; Ti = *Tricodesma indica*; At = *Asphodelphous tennufolius*; Si = *Sphaeranthus indica*; Ed = *Euphorbia drancenculoides*; Ca = *Chenopodium album*.

TABLE 2.—*Variance in the total vegetation and the species in the quadrats and strips of a 1 square meter area.*

Species	Quadrat	Strips N–S	Strips E–W	Average for strips	Efficiency	Density %
Total vegetation.....	75.815	388.17	355.32	371.45	1:4.5	——
Cyprus rotundus......	167.7	730.5	509.06	619.5	1:3.6	31.7
Asphodelphous tennufolius............	60.42	347.54	275.09	311.31	1:5.1	20
Chenopodium album. .	271.3	1,622.7	1,690	1,656.35	1:6	39.1
Sphaeranthus indica..	14.99	10.62	8.99	9.81	3:2	4.6
Euphorbia hirta	10.23	4.34	2.19	3.265	3:1	2.5
Tricodesma indica . .	4.42	1.17	0.92	1.045	4:1	0.95
Euphorbia dracenculoides.	2.04	0.66	0.83	0.745	2.9:1	0.85

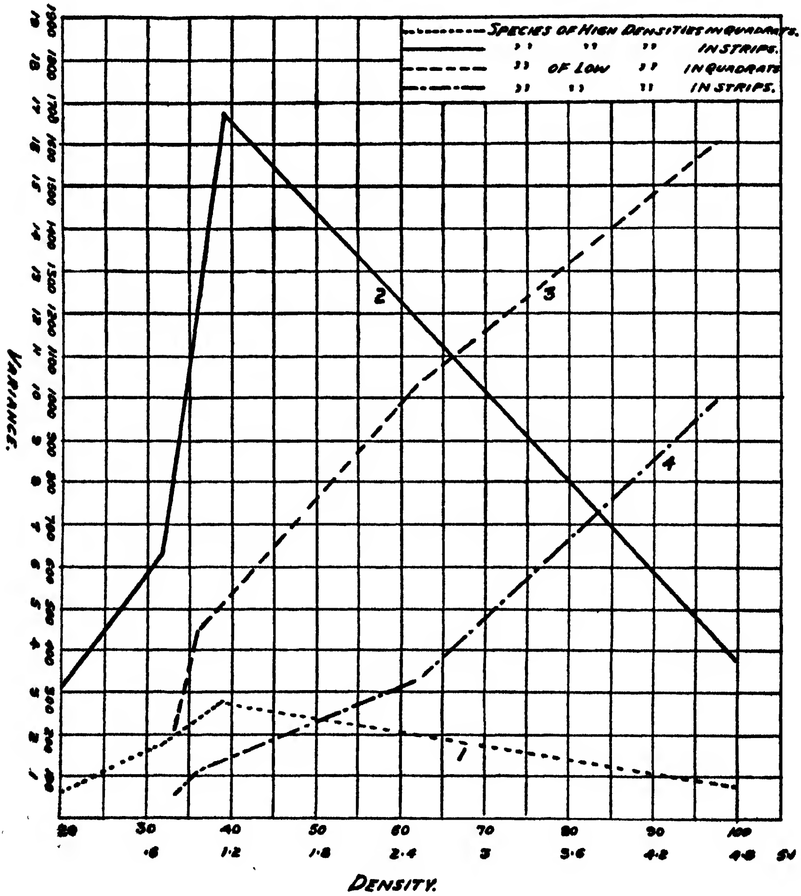

FIG. 1.—Comparison of the quadrat and strip methods of determining the weed flora of arable land.

random distribution is minimized. At the same time, with regard to the species of lower density where the dispersion seems to be random, the strips give a more accurate estimate, but the correct estimation of minor species may not be of singificant importance to the problem of weed control. As such, for all practical purposes, the usual method of quadrat listing or charting is more efficient and convenient.

SUMMARY

A test was made of the efficiency of the strip and the quadrat form of unit of estimating the weed flora of arable land. A sample quadrat of 25 square meters was taken and divided into 625 small squares. The variances of the total vegetation and the individual species were determined in square meter quadrats and in strips of the same area but five times longer than their breadth running in two directions at right angles to each other. The density of each species also was determined.

It was found that the quadrat of 1 square meter is the more efficient unit in a quantitative study of the weed flora of arable land.

The efficiency of this unit is confined to the species of higher densities only.

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THE EFFECT OF FERTILIZER APPLICATIONS ON THE COMPOSITION OF PASTURE GRASSES[1]

H. N. VINALL AND H. L. WILKINS[2]

THE relative productiveness of pastures in different localities depends not alone on the quantity of herbage produced but also on its quality. This perhaps is a truism which needs no explanation or defense. The factors which determine the quality of pasturage, however, are not so well understood and may warrant some discussion. In the first place, the kind of plants which contribute the pasturage are important. A reasonable percentage of legumes in the herbage increases its nutritive value because legumes have a higher feeding value than grasses. There is also an apparent difference in the nutritive value of various grasses.

The second important factor which has an effect on the nutritive value of pasture herbage is the fertility of the soil. A grass or legume grown on a rich soil will produce herbage richer in all the elements necessary for the proper nutrition of animals than will that same grass grown on a poor soil. This brings us directly to the question of the effect of applications of commercial fertilizers on the composition of the plant, a subject which will be discussed later. The value of certain of the rarer elements in pasturage is indicated by studies which are being made of the relation of malnutrition in animals to deficiencies of such elements as iron and copper in the herbage. "Salt-sick" of range cattle in Florida, described by Becker, Neal, and Shealy(1),[3] is a case in point. Cases of malnutrition due to phosphorus deficiencies have been reported in considerable number. These usually occur on pastures or ranges where the soil is deficient in available phosphorus or a soil in which the calcium-phosphorus ratio is unbalanced. In addition to these soil characteristics there is also a reported difference in the ability of plants to extract phosphorus from the soil.

But actual malnutrition effects from poor pastures are not the only features to be considered. There is also the other side of the picture which may be fully as important. That is the increased nutritive value of pasturage arising from the presence of these minerals in the soil. The superior livestock, especially race horses, produced on the bluegrass pastures of Kentucky may be explained in part, at least, by the high percentages of manganese, copper, cobalt, zinc, iron, and iodine found in bluegrass (6).

There is a third factor which has an effect on the nutritive value of pasturage, *viz.*, the stage of maturity of the plants at the time they

[1]Contribution from the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. The results from Beltsville, Md., were obtained in cooperation with the Bureau of Animal Industry, U. S. Dept. of Agriculture, the analyses in so far as the minerals are concerned being made by Dr. R. E. Davis, Assistant Biochemist of that Bureau. Also presented at the meeting of the Association of Southern Agricultural Workers, February 6, 1936, Jackson, Miss. Received for publication April 29, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 568.

are eaten. This, however, is a question of pasture management which may be adjusted by the operator.

COMPOSITION OF VARIOUS PASTURE GRASSES

The wide variation which exists in the composition of various grasses and even of the same grass grown under varying conditions, especially in respect to the crude protein content, has been recorded in numerous publications. Comparison of certain published data on the mineral content of various grasses show some striking differences in important respects. The selected analyses given in Table 1 are those of herbage produced in each case on unfertilized soil in the locality indicated and reflect a condition which is closely related to animal nutrition and, therefore, of prime importance in an appraisal of pasture values.

TABLE 1.—*Comparison of the mineral content of various pasture grasses grown under varying soil and climatic conditions without applications of fertilizer.*

Mineral element	Percentage of indicated mineral in the dry matter of various grasses grown in the states named						
	Bluegrass in Kentucky (McHargue, 6)	Bluegrass in Maryland (Wilkins, 10)	Carpet grass in S. Carolina* (Cooper, 2)	Bahia grass in Florida (Leukel, 5)	Carpet grass in Florida (Leukel, 5)	Centipede grass in Florida (Leukel, 5)	Wiregrass (healthy) in Florida (Neal, 8)
Calcium	0.470	0.491	0.318	0.880	0.972	0.493	0.230
Iron	0.032	——	0.034	——	——	——	0.0256
Magnesium	0.197	——	0.207	0.502	0.531	0.468	0.178
Manganese	0.008	——	0.048	——	——	——	——
Nitrogen	3.83	2.452	1.170	1.59	2.00	1.53	——
Phosphorus	0.952	0.379	0.149	0.366	0.272	0.285	0.276
Potassium	2.585	——	0.839	1.594	1.428	0.826	——
Silicon	3.02	——	0.313	——	——	——	——
Sodium	0.242	——	0.536	——	——	——	——
Sulfur	0.656	——	0.170	——	——	——	——

*The percentages are the average of 48 samples of carpet grass from the pasture fertilizer plats at the Coast Experiment Station, Summerville, S. C., 1930.

Such a comparison as the above would be decidedly more interesting and instructive if the analyses in other states had been as complete as those of McHargue in Kentucky and Cooper in South Carolina. Plans are being made to obtain more data as to the occurrence of the less common minerals in herbage through the use of a spectrograph. The data here given, however, indicate an apparently significant difference in the calcium, manganese, nitrogen, phosphorus, and potassium contents of various grasses when they are grown on different soil types. All of these minerals, with the possible exception of manganese, have a direct bearing on the nutritive value of the pasturage. The differences which occur in the phosphorus content of the bluegrass grown in Kentucky and that grown in Maryland can be explained only, it would seem, by the greater amount of available phosphorus in the Kentucky soil.

EFFECT OF COMMERCIAL FERTILIZERS ON COMPOSITION OF KENTUCKY BLUEGRASS AND WHITE CLOVER

There exists among investigators wide disagreement as to whether soil differences or applications of fertilizer affect the composition of the herbage significantly. English writers have repeatedly described certain of their pastures as "fatting" pastures and others as inferior or "non-fatting" pastures. These differences in pasturage value are ascribed to soil differences, but plant population studies have invariably shown a pronounced difference in the botanical composition of the vegetation on such pastures. We are, therefore, without information as to whether the same plant species growing on the various soil types in England would produce herbage differing in chemical composition.

Dr. Cooper (3) while located in New York studied the chemical composition of various pasture grasses growing on different soil types. He states that "The inverse relationship between the quantities of potassium and calcium in the plants analyzed would seem to indicate that the ash constituents of plants are largely determined by the amounts of these constituents which are available in the soil." Also, Forbes and his colleagues working with Kentucky bluegrass in Pennsylvania reported that the mineral composition of this grass was affected by the fertility of the soil.

Taylor (9) reports a consistent though slight increase in the calcium and phosphorus content of Dallis grass (*Paspalum dilatatum*) when this grass was limed and fertilized.

In direct opposition to these findings are the conclusions of several investigators. Mitchell (7) finds a wide variation in the ash content of varieties of the same species of plant grown under different conditions, but says that, "The iron, calcium, magnesium, and phosphorus content seem not to be affected by the fertilizer treatment received. Thus far there seems to be no definite relationship between the mineral content of the soils and the mineral content of the plants grown on them."

Unpublished data from the Florida Experiment Station covering 4 years' results from clipping grasses with a lawn mower at 10-day intervals show that annual applications of ammonium sulfate at the rate of 250 pounds per acre increased the average nitrogen content in the herbage as follows: Bahia grass, 5.6%; carpet grass, 10.4%; and centipede grass, 9.6%.

It is difficult to form any conclusion as to how fertilizers affect the chemical composition of pasture herbage by an examination of the literature on this subject. In many of the cases cited in publications the botanical composition of the plant population has been altered by the fertilizer and this in turn had its effect on the chemical composition of the herbage produced. An increased proportion of legumes invariably increases both the protein and minerals in the herbage, while a decrease in the legume percentage has the opposite effect. In some experiments at Beltsville, Md., care was observed to see that practically pure stands of the grass or legume were maintained and these experiments seem to prove rather conclusively that the composition of the herbage may be changed by fertilizer applications.

The plats from which these data were obtained were seeded in September 1928 on the Animal Husbandry farm at the National Agricultural Research Center, Beltsville, Md. Clippings with a lawn mower were made at irregular intervals whenever the growth was sufficient to warrant it, usually when it reached a height of 4 to 6 inches. The number of cuttings per year varied from four to six, depending on the rainfall. The clippings were collected in a "catcher" attached to the lawn mower, and after being weighed, representative composite samples were dried artificially in a drying room at medium temperatures reducing the moisture content to 10 or 12% after which a part of the sample was stored to await chemical analysis and the remainder was reduced to a moisture-free condition in an electric oven. The data for 1929 were not included because it was believed the fertilizer effects would not be fully apparent the year following seeding. In the 4 years of 1930 to 1933, including all the cuttings and pairing all the plats which had a given element in the fertilizer with plats the same in all respects except that the particular element was not included in the fertilizer, there are for the bluegrass a total of 56 comparable paired yields represented in the averages and for the white clover 49 paired yields. The statistical significance of the differences in percentages of the elements was determined by the formula $t = \sqrt{\frac{a^2 (n - 1)}{n b^2 - a^2}}$, which was derived algebraically from formulas given by Fisher (4). In this formula a = the algebraic sum of the differences; b = the sum of the squares of the differences; and n = the number (pairs) of comparisons.

The nitrogen in the herbage is recorded as protein (N × 6.25) since the term protein is more often used than nitrogen in expressing feed values.

All plats received an application of 8,000 pounds per acre of finely ground limestone when seeded in 1928. The fertilizer was applied annually at the following rates per acre N, 24 pounds; P, 64 pounds; and K, 50 pounds, whether alone or combined. Nitrogen was supplied in nitrate of soda, phosphorus in superphosphate, and potassium in muriate of potash. The fertilizer treatments were NPK, NP, PK, NK, O, N, P, and K.

Only the averages for the 4 years are given in Tables 2 and 3. Unfortunately, no determinations of the potassium content were made. The percentage of dry matter stated in each case is of no importance except to indicate the stage of maturity of the crop when cut.

The results of fertilizer applications on the composition of Kentucky bluegrass as shown in Table 2 indicate rather definitely a significant increase in many of the elements, the most important of which are protein, calcium, and phosphorus. Nitrogen applied in the fertilizer increased the crude protein 12.34% as an average of the 56 comparisons. According to Fisher, the probability (P) is less than 1 in 100 that this increase was due to chance. It is to be noted, however, that the increase was larger in the non-protein nitrogen than in the true protein. While the addition of phosphorus and potassium also resulted in an increase of crude protein, the percentage increase was much less than where nitrogen was added.

TABLE 2.—*The percentage of certain herbage constituents in the dry matter of Kentucky bluegrass on plats receiving annual applications of nitrate of soda, superphosphate, or muriate of potash as compared with herbage from plats which did not receive these fertilizers, Beltsville, Md., 1930–33.*

Herbage constituents	Average percentage of constituents in herbage from plats		Increase (+) or decrease (—) due to application of fertilizer element		Significance according to Fisher*	
	(A) With fertilizer element	(B) Without fertilizer element	(C) In actual percentage of dry matter	(D) In percentage of control C÷B	t	P
			Nitrate of Soda			
Dry matter	28.80	30.23	—1.43	—4.73	4.604	0.01
Ash	8.41	8.27	+0.14	+1.69	1.686	0.1
Ether extract	4.31	4.15	+0.16	+3.86	2.213	0.05
Crude fiber	25.38	25.67	—0.29	—1.13	2.082	0.05
Crude protein	18.02	16.04	+1.98	+12.34	7.268	0.01
"True" protein	13.89	12.80	+1.09	+8.52	6.375	0.01
Non-protein nitrogen	3.14	2.44	+0.70	+28.69	6.520	0.01
Nitrogen-free extract	44.88	46.67	—1.79	—3.84	5.730	0.01
Calcium	0.51	0.52	—0.01	—1.92	0.9001	0.4
Phosphorus	0.44	0.44	0.00	0.00	0.2271	0.8
			Superphosphate			
Dry matter	28.99	30.04	—1.05	—3.50	3.244	0.01
Ash	8.66	8.02	+0.64	+7.98	6.401	0.01
Ether extract	4.24	4.21	+0.03	+0.71	0.5362	0.6
Crude fiber	25.34	25.71	—0.37	—1.44	2.546	0.02
Crude protein	17.37	16.69	+0.68	+4.07	3.733	0.01
"True" protein	13.60	13.08	+0.52	+3.98	3.831	0.01
Non-protein nitrogen	2.87	2.71	+0.16	+5.90	1.698	0.1
Nitrogen-free extract	45.28	46.26	—0.98	-2.12	5.940	0.01
Calcium	0.56	0.48	+0.08	+16.67	6.038	0.01
Phosphorus	0.49	0.39	+0.10	+25.64	19.172	0.01
			Muriate of Potash			
Dry matter	28.83	30.20	—1.37	—4.54	4.520	0.01
Ash	8.57	8.11	+0.46	+5.67	6.548	0.01
Ether extract	4.24	4.22	+0.02	+0.47	0.3128	0.8
Crude fiber	25.60	25.45	+0.15	+0.59	1.064	0.3
Crude protein	17.26	16.80	+0.46	+2.74	2.422	0.02
"True" protein	13.48	13.21	+0.27	+2.04	1.949	0.05
Non-protein nitrogen	2.89	2.69	+0.20	+7.43	2.221	0.05
Nitrogen-free extract	45.23	46.32	—1.09	—2.35	5.468	0.01
Calcium	0.54	0.50	+0.04	+8.00	2.641	0.01
Phosphorus	0.45	0.44	+0.01	+2.27	3.168	0.01

*N = 56 pairs.

When phosphorus was applied in the fertilizer, the effect on the phosphorus content of the herbage was quite marked. An average increase of 25.64% of elemental phosphorus resulted in this case which would mean that the probability is less than 1 in 1,000 that this difference is due to chance. The *P* value is recorded as .01 in such cases because Fisher's table does not include higher values.

TABLE 3.—*The percentage of certain herbage constituents in the dry matter of white clover on plats receiving annual applications of nitrate of soda, superphosphate, or muriate of potash as compared with herbage from plats which did not receive these fertilizers, Beltsville, Md., 1930–33.*

Herbage constituents	Average percentage of constituents in herbage from plats		Increase (+) or decrease (—) due to application of fertilizer element		Significance according to Fisher*	
	(A) With fertilizer element	(B) Without fertilizer element	(C) In actual percentage of dry matter	(D) In percentage of control C÷B	t	P
			Nitrate of Soda			
Dry matter	18.28	18.27	+0.01	+0.05	0.0210	<0.9
Ash	12.15	11.66	+0.49	+4.20	2.343	0.02
Ether extract	03.34	03.35	—0.01	—0.30	0.2647	0.01
Crude fiber	15.67	15.74	—0.07	—0.44	0.4820	0.6
Crude protein	29.37	29.77	—0.40	—1.34	1.674	0.1
"True" protein	21.00	21.01	—0.01	—0.05	0.04150	<0.9
Non-protein nitrogen	06.29	06.59	—0.30	—4.55	1.754	0.1
Nitrogen-free extract	41.63	41.67	—0.04	—0.96	0.1765	0.8
Calcium	01.26	01.41	—0.15	—10.64	6.433	0.01
Phosphorus	0.50	0.49	+0.01	+2.04	1.413	0.2
			Superphosphate			
Dry matter	17.71	18.81	—1.10	—5.85	2.825	0.01
Ash	12.32	11.54	+0.78	+6.76	2.948	0.01
Ether extract	03.30	03.37	—0.07	—2.08	1.465	0.2
Crude fiber	15.51	15.81	—0.30	—1.90	1.653	0.1
Crude protein	29.98	29.21	+0.77	+2.64	2.917	0.01
"True" protein	21.03	21.02	+0.01	+0.05	0.061	<0.9
Non-protein nitrogen	06.73	06.17	+0.56	+9.08	3.446	0.01
Nitrogen-free extract	41.11	42.13	—1.02	—2.42	3.520	0.01
Calcium	01.41	01.26	+0.15	+11.90	7.495	0.01
Phosphorus	0.55	0.45	+0.10	+22.22	9.645	0.01
			Muriate of Potash			
Dry matter	17.50	19.02	—1.52	—7.99	5.136	0.01
Ash	12.60	11.26	+1.34	+11.90	5.401	0.01
Ether extract	03.36	03.33	+0.03	+0.90	0.5926	0.6
Crude fiber	15.75	15.59	+0.16	+1.03	1.083	0.3
Crude protein	29.60	29.59	+0.01	+0.03	0.0634	<0.9
"True" protein	21.18	20.85	+0.33	+1.58	2.077	0.05
Non-protein nitrogen	06.33	06.58	—0.25	—3.80	1.328	0.2
Nitrogen-free extract	40.82	42.42	—1.60	—3.77	6.558	0.01
Calcium	01.33	01.34	—0.01	—0.75	0.9634	0.3
Phosphorus	0.50	0.49	+0.01	+2.04	1.279	0.2

*N = 49 pairs.

The application of phosphorus to the soil also resulted in an increase of 16.67% in the calcium content of the herbage. The phosphorus was applied as superphosphate which contains approximately 25% calcium, but it is unlikely that the increase in calcium can be attributed to this fact since 8,000 pounds per acre of ground limestone were applied in 1928 to all the plats. Evidently adequate avail-

able phosphorus in the soil enables the grass to utilize larger amounts of calcium.

Unfortunately, the potassium in the herbage was not determined, hence the effect of adding potash in the fertilizer is not measured effectively. The increases in the percentages of crude protein, phosphorus, and calcium in the herbage, while small, were consistent and therefore appear to be significant.

As would be expected with the increase in the percentages of other elements, there was a corresponding decrease in the percentage of nitrogen-free extract in each case. The percentage of crude fiber also decreased slightly except in the potassium comparisons. The effect on the percentage of ether extract was hardly significant in any case.

If statistical methods are sound these results prove beyond reasonable doubt that the composition of a grass may be changed appreciably by applications of fertilizer to the soil on which it is grown. These plats of Kentucky bluegrass were hand weeded during the course of this experiment and no contamination with other plants was allowed.

The results obtained with white clover differ from those given for bluegrass in that there was no increase in the protein content resulting from applications of nitrogen in the fertilizer. For this reason and because there is a strange and probably significant decrease in the calcium content of the herbage when nitrogen was applied in the fertilizer, the results of a similar study of white clover are given in Table 3.

An examination of Table 3 reveals some rather disconcerting facts regarding the effect of applying nitrogen fertilizers to white clover. These plats were hand weeded in the same way as those of Kentucky bluegrass and the herbage analyzed was approximately pure clover. Disregarding dry matter, in seven of the nine herbage constituents there was a decrease resulting from nitrogen applications to the soil. All forms of nitrogen were included in these decreases, but the largest decrease, 10.64%, occurred in calcium. The probability (P) is less than 1 in 100 that this decrease in calcium was due to chance.

Additions of phosphorus to the soil had a much more favorable influence on the composition of white clover. Small increases occurred in all forms of nitrogen, but this was least in the true protein most of the increase being in non-protein nitrogen. There was an increase of 22.22% in phosphorus and 11.9% in calcium, both of which are significant.

White clover apparently benefited also from the addition of potassium in the fertilizer. Small increases were recorded in six of the nine herbage constituents all of which, with the exception of crude fiber, are important from the standpoint of animal nutrition. The only decrease in elements of nutritional value was an almost insignificant one in calcium.

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THE PHYSICAL CHANGES IN SOILS OF THE SOUTHERN HIGH PLAINS DUE TO CROPPING AND WIND EROSION AND THE RELATION BETWEEN THE $\frac{\text{SAND} + \text{SILT}}{\text{CLAY}}$ RATIOS IN THESE SOILS[1]

HARLEY A. DANIEL[2]

CONSIDERABLE research (4, 6, 9, 10, 13)[3] has been conducted on the effect of water erosion on the physical properties of erosive and non-erosive soils in the humid regions, however, very little information is available on the physical properties of soils affected by wind erosion in the southern high plains of the United States. Some studies on soil drifting were made in Canada by Moss (11), who found that the drift from the medium- and coarse-textured soils contained more sand and less silt and clay than the undrifted soil, while the mechanical composition of fine-textured soils and the drift was almost identical.

The factors affecting water erosion were studied by Lutz (7) and he found that Davidson clay, a comparatively non-erosive soil, contained a higher percentage of clay than the Iredell sandy clay, an erosive type of soil. He states that the erosiveness of the Iredell was due to the ease with which it dispersed and its impermeability to water, while the non-erosive nature of the davidson was due to the high state of flocculation of its finer mechanical separates into porous, stable granules which resist dispersion and permit a rapid percolation of water through the soil profile.

Middleton (8) states that, "the properties having the greatest influence on soil erosion are indicated by dispersion ratio, ratio of colloids to moisture equivalent, erosion ratio and silica-sesquixide ratio."

Bouyoucos (1) made a comparison between the $\frac{\text{sand}+\text{silt}}{\text{clay}}$ ratio or the so-called "clay ratio" and Middleton's erosion ratio and stated that, "with few exceptions, both ratios tend to run parallel in the same soils and tend to indicate about the same thing in regard to the possible behavior of soils towards erosion." From this information Bouyoucos suggested the possibility that the clay ratio might be employed as a criterion of erosion as well as the erosion ratio.

EXPERIMENTAL PROCEDURE

Composite samples of cropped, virgin, sub-surface, and the drifted soils were collected in or near the Oklahoma Panhandle during the fall and winter of 1935–

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[3]Figures in parenthesis refer to "Literature Cited", p. 580.

36. The sub-surface soils included in Table 1 were composite samples of the cropped and virgin soils, but separate samples were taken in order to make a comparison of these soils.

The cropped, virgin, and soil drift samples were taken from adjacent areas, and in all cases within 100 yards of each other. The depth at which the surface samples were taken varied from 0 to 12 inches and the sub-surface from 12 to 18 inches. The samples of drift were collected from the hummocks and the sand dunes that formed around fences or other stationary objects. These soils were air-dried, pulverized with a roller, and the sand, silt, and clay content determined by Bouyoucos' hydrometer method, using sodium-hydroxide and sodium oxalate as dispersing agent.

RESULTS

THE SAND, SILT, AND CLAY CONTENT OF CROPPED, VIRGIN, AND DRIFTED SOILS OF THE SOUTHERN HIGH PLAINS

In order to obtain information in regard to the physical properties of the soils collected from virgin areas, cropped land, and soil drifts, mechanical analyses were made to determine the percentage of sand, silt, and clay in each sample. These soils were separated into three major groups based on the clay content of the virgin surface according to Davis and Bennett's (2) classification and the data are recorded in Table 1. Although there was a considerable variation in the individual samples, the greatest difference between the drift and virgin soil occurred in the coarse- and medium-textured soils. The drifted soil from areas containing a high quantity of clay had a slightly higher percentage of sand and less silt and clay than the virgin surface, but the difference was not as great as that which occurred in the coarse-textured soils.

The mean sand, silt, and clay contents of these soils were calculated and are given in Table 2. The virgin soil was used as a standard and the difference in percentage composition of these constituents were calculated for the cropped, sub-surface, and drifted soils. The average data show that the cropped surface contained 4.0% more sand and 5.3% less silt and clay and the drift 29.3% more sand and 37.8% less silt and clay than adjacent virgin areas. When the average sand, silt, and clay contents of each group of soils were calculated and these constituents in the drift compared with soil which had not been cultivated, the drifts contained 22.3% more sand and 53.1% less silt and clay on the coarse-textured, 37.8% more sand and 38.6% less silt and clay on the medium-textured, and 31.1% more sand and 20.1% less silt and clay on the fine-textured soils.

According to these data, the percentage of sand in the drift increased in proportion to the amount of silt and clay removed by the wind. The average sum of the difference in percentage composition of the drift and the virgin surface soil was 16.5 for sand and — 16.5 for silt and clay. The total amount of sand in a particular soil does not change, but the percentage increases due to wind erosion. The fine particles are removed in the shifting of the soil and consequently the coarse material remained in the dunes and hummocks. Fig. 1, which is representative of thousands of drifts in the high plains in 1935, also gives conclusive evidence of this situation.

TABLE 1.—*The sand, silt, and clay contents of soils of the southern high plains and the*

Sample No.	Place collected	Virgin surface					Cropped surface		
		Sand %	Silt %	Clay %	Clay ratio	Class*	Sand %	Silt %	Clay %
							Virgin Surface 20% or Less		
42	3 mi. S. Goodwell	65.5	17.9	16.6	5 02	Sandy loam	60.4	18.0	21.6
63	19 mi. N. Goodwell	70.6	13.0	16.4	5.09	Sandy loam	73.2	12.4	14.4
75	4 mi. N. W. Hooker	57.4	22.6	20.0	4.00	Sandy loam	67.0	15.8	17.2
106	10 mi. E Turpin	66.2	18.6	15.2	5 57	Sandy loam	68.0	12.8	19.2
111	6 mi. S. Turpin	72.5	16.1	11.4	7.77	Sandy loam	73.0	13.2	13.8
115	4 mi. S. Turpin	56.3	23 9	19.8	4.05	Sandy loam	57.6	21.3	21.1
127	6 mi. S. Beaver	62.6	18.2	19.2	4.20	Sandy loam	58.0	22.8	19.2
151	11 mi. N. Goodwell	75.0	11.4	13.6	4 35	Sandy loam	82.4	5.4	12.2
155	12 mi. N. Goodwell	66.0	16.8	17.2	4 81	Sandy loam	89.2	2.8	8.0
170	1 mi. E. Hooker	58.3	24.5	17 2	4.81	Sandy loam	56.8	14.0	29.2
174	2 mi. N. E. Tyrone	68.6	18.0	13.4	6.46	Sandy loam	65.3	18.0	16.7
230	6 mi. W. 3 S. Texhoma	71.6	12.8	15.6	5.41	Sandy loam	74.6	11.0	14.4
240	6 mi. W. Texhoma	74.4	10.6	15.0	5 66	Sandy loam	71.4	9.6	19.0
285	21 mi. S. W. Texhoma	66.2	13.8	20 0	4 00	Sandy loam	64.2	11.4	24.4
317	6 mi. S. Chamberlin, Texas	70 8	13 2	16.0	5 25	Sandy loam	75 2	8.0	16.8
322	Eberle-SCS-P-Dalhart, Texas	70.2	9 8	20.0	4 00	Sandy loam	59.8	15.8	24.4
334	6 mi. S. W. Conlin, Texas	65.4	16.4	18.2	4 49	Sandy loam	50 4	15.4	34.2
339	3 mi. W. Conlin, Texas	81.0	5.0	14.0	6.14	Sand	77 4	9.4	13.2
344	4 mi. S. Conlin, Texas	81.4	10.0	8.6	10 62	Sand	76 0	11.4	12.6
349	1 mi. W. Conlin, Texas	59.0	22.0	19.0	4 27	Sandy loam	63.4	20.6	16.0
354	Casey-SCS-P-Dalhart, Texas	88 0	4 8	7 2	12 88	Sand	94.0	3.4	2.6
360	1 mi. S. Chamberlin, Texas	80.4	7.6	12.0	7.33	Sand	78.0	5.4	16.6
396	16 mi. S. E. Elkhart, Kansas	76.0	8.0	16 0	5 25	Sandy loam	74.0	10.4	15.6
411	4 mi. S. Campho, Colorado	85.6	8 0	6 4	14 62	Sand	87.6	7.0	5.4
							Virgin Surface 20 to 30%		
59	4 mi. E. 2 N. Goodwell	62 6	14 0	23 4	3 27	Sandy clay loam	60.6	19 6	19 8
71	2 mi. N. 3 E. Mouser	52 0	23 9	24 1	3 14	Sandy clay loam	61.0	16.2	22.8
89	2 mi. N. Hooker	42.8	32 0	25 2	2 96	Clay loam	54.8	24 6	20.6
87	3 mi. E. Optima	61.6	17 4	21 0	3 76	Sandy clay loam	68.4	12.4	19.2
96	14 mi. E. Guymon	46.0	29 6	24 4	3 09	Clay loam	47.4	25.6	27.0
102	18 mi. E. Hardesty	39 0	36.0	25 0	3 00	Clay loam	45.6	30.0	24.4
123	2 mi. S. E. Forgan	55.4	16.6	28 0	2 57	Sandy clay loam	54.6	22.4	23.0
131	20 mi. S. Beaver	32 8	37 8	29 4	2 40	Clay loam	28.8	35.8	35.4
147	½ mi. W. Goodwell	45 4	27.6	27 0	2 70	Clay loam	42.1	26 7	31.2
162	10 mi. N. Guymon	51.9	22 2	25 9	2.86	Sandy clay loam	56.8	17.4	25.8
215	6 mi. S. 4 W. Goodwell	54 6	18 0	27.4	2.64	Sandy clay loam	60.2	19.0	20.8
225	4 mi. S. Goodwell	44.0	28 8	27.2	2 67	Clay loam	48.2	25.0	26.8
235	7 mi. S. Goodwell	56 8	21 8	21 4	3 67	Sandy clay loam	60.2	18.4	21.4
245	3 mi. W. Texhoma	49 2	23.0	27 8	2 59	Clay loam	50.6	24.4	25.0
280	8 mi. S. Texhoma	57 6	20 0	22.4	3 46	Sandy clay loam	71.0	13.6	15.4
290	23 mi. N. E. Dumas, Texas	43 4	27.8	28.8	2.47	Clay loam	42.6	27.8	29.6
295	5 mi. S.W. Texhoma	40.4	30.0	29.6	2 37	Clay loam	49.8	26.0	24.2
300	15 mi. S.W. Texhoma	48.2	22.0	29 8	2 35	Clay loam	48.6	24.6	26.8
305	3 mi. W. 1 S. Texhoma	45.2	25.0	29.8	2 35	Clay loam	56.0	22.4	21.6
312	5 mi. S. Chamberlin, Texas	48.6	23.4	28 0	2 57	Clay loam	50.8	19.2	30.0
327	4 mi. S. W. Stratford, Texas	51.8	24.0	24 2	3 13	Sandy clay loam	44.0	21.2	34.8
366	Peden-SCS-P-Dalhart, Texas	57.0	18 0	25.0	3 00	Sandy clay loam	64.0	18.4	17.2
371	Casey-SCS-P-Dalhart, Texas	51 4	23 6	25 0	3 00	Sandy clay loam	55.6	19.1	25.3
391	13 mi. W. Guymon	66 0	12 4	21 0	3 62	Sandy clay loam	61.4	18.6	20.0
406	3 mi. S. 5 W. Keyes	55 6	23.0	21.4	3 67	Sandy clay loam	64.0	17.6	18.4
416	16 mi. N. Boise City	53 0	23.0	24 0	3 16	Sandy clay loam	57.0	17.8	25.2
							Virgin Surface Over 30% Clay		
46	5 mi. S. 2 E. Goodwell	46.0	16.8	37.2	1 68	Clay	54.2	19.2	26.6
67	1 mi. S. E. Hough	37.8	28 8	33.4	1.99	Clay	39.6	26.0	34.4
92	4 mi. E. Guymon	42.8	19.2	38.0	1.63	Clay	45.2	21.4	33.4
140	1 mi. W. Farnsworth, Texas	33.4	31.6	35.0	1 85	Clay	32.2	35.6	32.2
166	4 mi. W. 1½ N. Goodwell	39.8	26.6	33.6	1.97	Clay	45.2	22.5	32.3
178	3 mi. W. 2 N. Goodwell	41.1	24.9	34.0	1 94	Clay	47.5	21.5	31.0
185	3 mi. N. 1 W. Goodwell	33.7	28.9	37 4	1 67	Clay	43.1	18.5	38.4
220	6 mi. S. 1 W. Goodwell	36.0	32.8	31.2	2.20	Clay	43.4	25.0	31.6
386	Pan. Agr. Exp. Sta. Goodwell	44.4	25.5	30.1	2 32	Clay	47.0	25.0	28.0
401	5 mi. S. E. Keyes	42.6	26.0	31.4	2.18	Clay	43.6	20.0	36.4
421	3 mi. S. 9 E. Keyes	34 0	26.5	30 5	1.54	Clay	34.0	27.0	39.0

*Based on Davis and Bennett's (2) classification.
†Samples collected from dunes that have been shifted at least four times.
‡Samples collected from new dunes formed during the first dust storms of 1936.

relation between the $\frac{sand + silt}{clay}$ *ratios in these soils and the soil drift.*

Cropped surface		Sub-surface					Soil drift				
Clay ratio	Class*	Sand %	Silt %	Clay %	Clay ratio	Class*	Sand %	Silt %	Clay %	Clay ratio	Class*
Clay "Coarse-textured Soils"											
3.62	Sandy clay loam	65.5	17.9	16.6	5.02	Sandy loam	85.8	6.2	8.0	11.51	Sand
5.94	Sandy loam	65.2	14.4	20.4	3.90	Sandy clay loam	83.6	7.6	9.8	9.20	Sand
4.81	Sandy loam	59.6	11.8	28.6	2.49	Sandy clay loam	63.0	19.4	17.6	4.68	Sandy loam
4.20	Sandy loam	67.4	9.4	23.2	3.31	Sandy clay loam	86.8	5.0	8.2	11.19	Sand
6.25	Sandy loam	73.6	10.0	16.4	5.09	Sandy loam	91.0	2.2	6.8	13.70	Sand
3.73	Sandy clay loam	49.0	17.2	33.8	1.95	Clay	74.6	10.4	15.0	5.66	Sandy loam
4.20	Sandy loam	57.2	11.8	31.0	2.22	Sandy clay	87.6	2.6	9.8	9.20	Sand
7.19	Sand	82.4	5.4	12.2	7.19	Sand	84.0	6.4	9.6	9.42	Sand
11.50	Sand	76.0	9.0	15.0	5.66	Sandy loam	96.0	1.0	3.0	32.33†	Sand
2.42	Sandy clay loam	49.3	21.5	29.2	2.42	Clay loam	72.3	12.5	15.2	5.57	Sandy loam
4.98	Sandy loam	56.8	15.5	27.7	2.61	Sandy clay loam	89.3	2.5	8.2	11.19	Sand
5.94	Sandy loam	64.4	14.3	21.3	3.69	Sandy clay loam	90.2	0.8	9.0	10.11	Sand
4.26	Sandy loam	56.2	14.0	29.8	2.35	Sandy clay loam	87.8	3.8	8.4	10.90	Sand
3.09	Sandy clay loam	61.8	10.7	27.5	2.63	Sandy clay loam	78.0	8.0	14.0	6.14	Sandy loam
4.95	Sandy loam	71.7	8.4	19.9	4.02	Sandy loam	87.4	3.0	9.6	9.41†	Sand
3.09	Sandy clay loam	60.2	13.1	26.7	2.74	Sandy clay loam	90.8	4.4	4.8	19.83†	Sand
1.92	Sandy clay	48.5	14.8	36.7	1.72	Clay	78.8	14.0	7.2	12.88†	Sandy loam
6.57	Sandy loam	77.8	5.6	16.6	5.03	Sandy loam	87.4	5.6	7.0	13.28	Sand
6.93	Sandy loam	66.8	13.9	19.3	4.18	Sandy loam	94.0	2.0	4.0	24.00†	Sand
5.25	Sandy loam	61.0	16.0	23.0	3.34	Sandy clay loam	90.0	5.4	4.6	20.73	Sand
37.46	Sand	83.7	7.7	8.6	10.62	Sand	94.4	3.4	2.2	44.45†	Sand
5.02	Sandy loam	67.6	9.2	23.2	3.31	Sandy clay loam	97.0	1.0	2.0	49.00†	Sand
5.41	Sandy loam	72.6	7.8	19.6	4.10	Sandy loam	80.4	6.0	13.6	6.35‡	Sand
17.51	Sand	70.8	12.5	16.7	4.98	Sandy loam	96.6	1.0	2.4	40.66	Sand
Clay "Medium-textured Soil"											
4.05	Sandy loam	54.6	25.6	19.8	4.05	Sandy loam	66.2	15.4	18.4	4.43	Sandy loam
3.38	Sandy clay loam	51.4	20.8	27.8	2.59	Sandy clay loam	79.2	7.6	13.2	6.57	Sandy loam
3.85	Sandy clay loam	54.8	17.6	27.6	2.62	Sandy clay loam	46.4	32.8	20.8	3.80	Clay loam
4.20	Sandy loam	69.8	12.4	17.8	4.61	Sandy loam	82.0	5.6	12.4	7.06	Sand
2.70	Clay loam	50.6	15.6	33.1	1.95	Sandy clay	48.0	28.0	24.0	3.16	Clay loam
3.09	Clay loam	40.8	28.2	31.0	2.22	Clay	63.7	17.1	19.2	4.20	Sandy loam
3.34	Sandy clay loam	73.4	6.8	19.8	4.05	Sandy loam	72.0	9.0	19.0	4.26	Sandy loam
1.82	Clay	21.8	29.2	49.0	1.04	Clay	37.0	28.0	35.0	1.86	Clay
2.20	Clay	36.8	20.2	43.0	1.32	Clay	69.4	10.4	20.2	3.95	Sandy clay loam
2.87	Sandy clay loam	47.8	14.4	37.8	1.64	Clay	54.6	21.0	24.4	3.09	Sandy clay loam
3.80	Sandy clay loam	52.9	19.5	27.6	2.62	Sandy clay loam	80.6	8.0	11.4	7.77	Sand
2.73	Clay loam	42.5	22.5	35.0	1.85	Clay	67.0	10.4	22.6	3.42	Sandy clay loam
3.67	Sandy clay loam	59.5	15.6	24.9	3.01	Sandy clay loam	65.4	14.4	20.2	3.95	Sandy clay loam
3.00	Sandy clay loam	46.3	23.5	30.2	2.31	Clay	56.6	16.8	26.6	2.75	Sandy clay loam
5.49	Sandy loam	59.9	15.5	24.6	3.06	Sandy clay loam	68.8	17.0	14.2	6.04	Sandy loam
2.37	Clay loam	29.6	18.8	51.6	0.93	Clay	75.8	7.6	16.6	5.02	Sandy loam
3.13	Sandy clay loam	45.5	23.1	31.4	2.18	Clay	81.2	6.8	12.0	7.33	Sand
2.73	Clay loam	33.3	18.7	48.0	1.08	Clay	77.2	8.8	14.0	6.14	Sandy loam
3.62	Sandy clay loam	58.6	14.6	26.8	2.73	Sandy clay loam	64.0	18.8	17.2	4.81	Sandy loam
2.33	Sandy clay	47.3	18.1	34.6	1.89	Clay	66.8	9.0	24.2	3.13	Sandy clay loam
1.87	Clay	55.5	21.0	23.5	3.25	Sandy clay loam	73.2	12.2	14.6	5.84	Sandy loam
4.68	Sandy loam	58.7	13.7	27.6	2.62	Sandy clay loam	92.0	5.0	3.0	32.33†	Sand
2.95	Sandy clay loam	53.7	15.0	31.3	2.19	Sandy clay	97.0	1.0	2.0	49.00†	Sand
4.00	Sandy clay loam	64.4	10.2	25.4	2.93	Sandy clay loam	67.4	12.0	20.6	3.85‡	Sandy clay loam
4.43	Sandy loam	58.1	19.2	22.7	3.40	Sandy clay loam	85.6	6.4	8.0	11.50	Sand
2.96	Sandy clay loam	42.1	22.4	35.5	1.81	Clay	72.0	10.4	17.6	4.68‡	Sandy loam
"Fine-textured Soil"											
2.75	Sandy clay loam	44.6	31.4	24.0	3.16	Clay loam	66.8	11.6	21.6	3.62	Sandy clay loam
1.90	Clay	31.8	20.6	47.6	1.10	Clay	45.0	27.0	28.0	2.57	Clay loam
1.99	Clay	42.0	10.4	47.6	1.10	Clay	53.4	16.6	30.0	2.33	Sandy clay
2.10	Clay	26.0	25.0	49.0	1.04	Clay	45.0	25.0	30.0	2.33	Clay
2.09	Clay	35.8	24.5	39.7	1.51	Clay	49.7	20.5	29.8	2.35	Clay loam
2.22	Clay	42.0	19.3	38.7	1.58	Clay	45.0	18.0	37.0	1.70	Clay
1.60	Clay	33.1	26.5	40.4	1.47	Clay	39.7	20.9	39.4	1.54	Clay
2.16	Clay	39.3	23.2	37.5	1.66	Clay	60.4	15.6	24.0	3.16	Sandy clay loam
2.57	Clay loam	46.0	20.0	34.0	1.94	Clay	62.4	15.6	22.0	3.54‡	Sandy clay loam
1.74	Clay	44.6	25.0	30.4	2.28	Clay	52.6	19.0	28.4	2.52	Sandy clay loam
1.56	Clay	33.0	25.0	42.0	1.38	Clay	46.0	19.0	35.0	1.85‡	Clay

TABLE 2.—*The mean sand, silt, and clay contents in soils of the Southern high plains, the $\frac{sand+silt}{clay}$ ratios, and the difference between these constituents in the virgin soil and that of cropped, sub-surface, and drifted soils.*

Kind of soil	No. of samples analyzed	Sand			Silt			Clay			Silt and Clay			$\frac{\text{Sand+silt}}{\text{clay}}$ ratios
		Per cent in soil	Difference in soils*		Per cent in soil	Difference in soils*		Per cent in soil	Difference in soils*		Per cent in soils*	Difference in soil		
			Sum	%		Sum	%		Sum	%		Sum	%	
"Coarse-textured Soils" Virgin Surface 20% or Less Clay														
Virgin surface...	24	70.4	—	—	14.3	—	—	15.3	—	—	29.6	—	—	5.53
Cropped surface	24	70.7	0.3	00.4	12.3	—2.0	—14.0	17.0	1.7	11.1	29.3	—0.3	—1.1	4.88
Sub-surface.....	24	65.2	—5.2	-7.4	12.2	—2.1	—14.7	22.6	7.3	47.7	34.8	5.2	17.5	3.42
Soil drift.......	24	86.1	15.7	22.3	5.6	—8.7	—60.9	8.3	—7.0	—45.8	13.9	—15.7	—53.1	11.04
"Medium-textured soils" Virgin Surface 20% to 30% Clay														
Virgin surface...	26	50.5	—	—	23.9	—	—	25.6	—	—	49.5	—	—	2.90
Cropped surface.	26	54.0	3.5	6.9	21.7	—2.2	—9.3	24.3	—1.3	—5.1	46.0	—3.5	—7.1	3.11
Sub-surface.....	26	50.4	—0.1	—0.2	18.5	—5.4	—22.6	31.1	5.5	21.4	49.6	0.1	0.2	2.21
Soil drift.......	26	69.6	19.1	37.8	13.0	—10.9	—45.7	17.4	—8.2	—32.1	30.4	—19.1	—38.6	4.74
"Fine-textured Soils" Virgin Surface Over 30% Clay														
Virgin surface...	11	39.2	—	—	26.2	—	—	34.6	—	—	60.8	—	—	1.89
Cropped surface.	11	43.2	4.0	10.2	23.8	—2.4	—9.2	33.0	—1.6	—4.7	56.8	—4.0	—6.6	2.03
Sub-surface	11	38.0	—1.2	—3.1	22.8	—3.4	—13.0	39.2	—4.6	13.2	62.0	1.2	1.9	1.55
Soil drift.......	11	51.4	12.2	31.1	19.0	—7.2	—27.5	29.6	—5.0	—14.5	48.6	—12.2	—20.1	2.37
Average of All Samples														
Virgin surface...	61	56.3	—	—	20.5	—	—	23.2	—	—	43.7	—	—	3.31
Cropped surface.	61	58.6	2.3	4.0	18.4	—2.1	—10.3	23.0	0.2	—0.9	41.4	—2.3	—5.3	3.34
Sub-surface.....	61	54.0	—2.3	—4.1	16.8	—3.7	—18.1	29.2	6.0	25.8	46.0	2.3	5.2	2.42
Soil drift.......	61	72.8	16.5	29.3	11.2	—9.3	—45.6	16.0	—7.2	—31.1	27.2	—16.5	—37.8	5.25

*Virgin surface soil used as standard.

The data in Table 1 and the picture seems to indicate that the more a soil is shifted, the more sand content of the material increases and the more susceptible it becomes to wind erosion. The drift from nine different soils that have been shifted at least four times contained 73.0% less silt and clay and 31.28% more sand than the respective virgin surface. The average composition of these drifts was 91.9% sand, 3.9% silt, and 4.2% clay, while that for the virgin soil was 70% sand, 13.4% silt, and 16.6% clay. The greatest changes due to wind erosion were found in soils Nos. 366 and 371. The drift

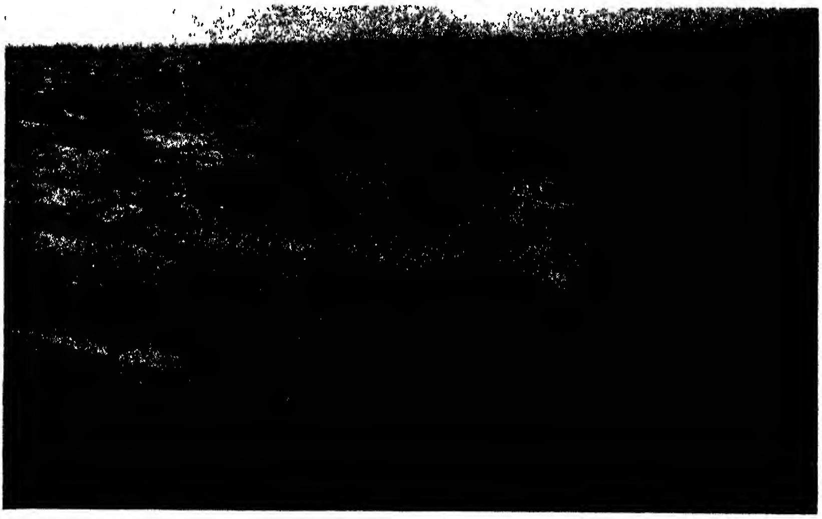

FIG. 1.—A country road filled with sand after a wind storm in the Oklahoma Panhandle, April, 1935.

from these soils contained 92.0% and 97.0% sand and the virgin surface 57.0% and 51.4% sand, respectively. Samples from five different areas were collected after the first storms of 1936 from newly formed dunes and the drift averaged 24.1% less silt and clay and 20.0% more sand than the virgin soil. Since the silt and clay content of drifts in some fields has already decreased over 85%, these results show that a large amount of the high plains land may eventually become badly eroded, as shown in Fig. 2, with little or no economical value, if wind erosion continues.

Although the results indicate that the drifted soil contains considerably less silt and clay than the virgin soil, not all of this material was removed from the high plains since fine particles picked up by the wind often settle in an adjacent area. Murphy (12) found that dust was deposited at an average rate of 82.1 pounds per acre in central Oklahoma as a result of storms occurring in the high plains during March and April of last year. This is evidence that a large amount of the finer particles, as shown in Fig. 3, is carried away by wind erosion. Fig. 4 represents the condition of thousands of acres

of land in the Panhandle in 1935. This picture also gives conclusive evidence that considerable quantities of soil had been removed, but more careful research possibly should be conducted before the exact amount of fine material that drifted away from the high plains in dust can be determined.

FIG. 2.—A destructive effect of wind erosion on shallow sandy loam soils (caliche exposed).

In spite of the severe damage caused by wind erosion, surveys made by the Soil Conservation Service (14) show that of all the soils eroded by wind in Texas, only about 5.9% was classed as sub-margin-

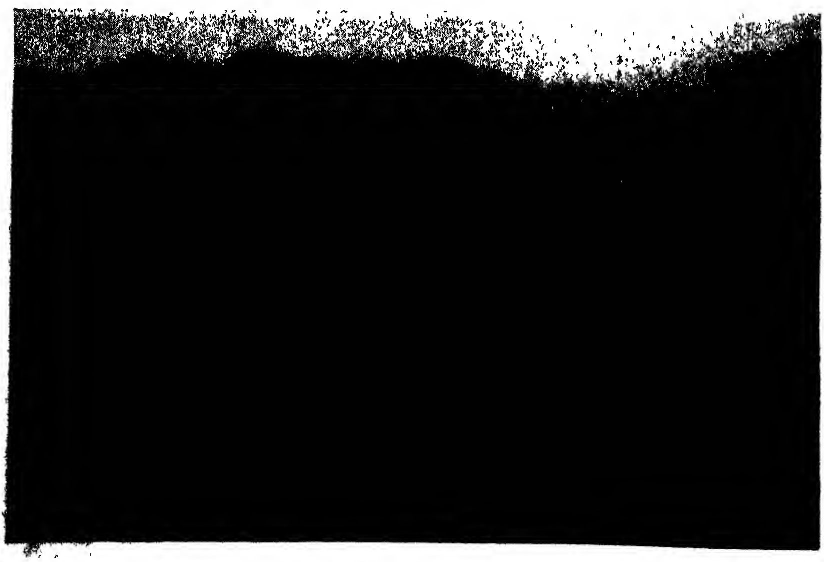

FIG. 3.—The great black dust storm that swept the plains, April 14, 1935.

al land, due to erosion. In order to prevent some of the best wheat and grass land of the United States from becoming hummocks of and or a "man-made desert" (5), every possible economical means should be used to prevent wind erosion.

The sub-surface soils contained an average of 4.1% less sand and 5.2% more silt and clay than the virgin surface. As the sub-soil had an average of 18.1% less silt than the virgin surface and 10.3% less than the cropped surface, apparently that was the reason why more silt was removed from the drifts than clay. The drift had an average of 45.6% less silt and 31.1% less clay than the virgin, which seems to agree with information reported by Fly (3) on the mechanical an-

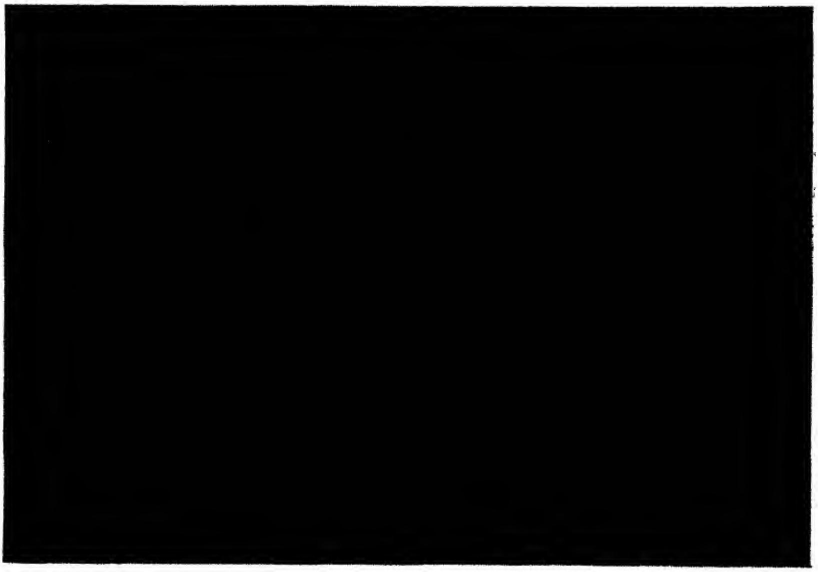

FIG. 4.—A field after the windy season of 1935 in the Oklahoma Panhandle. The marks represent the point of listers showing that the surface soil had been removed to the depth of cultivation.

alysis of dust. He found that the average mechanical analysis of dust deposited by wind in buildings at Goodwell, Oklahoma, was 62.5% silt, 23.2% clay, and 14.3% very fine sand.

The sand, silt, and clay contents of cropped and virgin sub-surface soils were studied and the data given in Table 3. These data show that there was very little difference in the mechanical analysis of these soils. All of the comparisons between cropped and virgin soils were similar except nine, which did not exceed one soil class. Six of the cropped soils and three of the virgin soils had a finer textured sub-surface than the adjacent other soils. The average of mechanical analysis of cropped samples was 56.1% sand, 15.9% silt, and 28.0% clay, while the average of the virgin soils was 55.4% sand, 16.6% silt, and 28.0% clay. The average clay ratio was identically the same for

TABLE 3.—*The mechanical analysis of the cropped and virgin sub-surface soils in the southern high plains.*

Sample No.	Place collected	Cropped sub-surface					Virgin sub-surface				
		Sand %	Silt %	Clay %	Ratio	Class*	Sand %	Silt %	Clay %	Ratio	Class*
216	6 mi. S. 4 W. Goodwell	54.6	18.0	27.4	2.64	Sandy clay loam	51.2	21.0	27.8	2.59	Sandy clay loam
221	6 mi. S. 1 W. Goodwell	39.6	22.0	38.4	1.60	Clay	39.0	24.4	36.6	1.73	Clay
226	4 mi. SW Goodwell	42.8	21.0	36.2	1.76	Clay	42.2	24.0	33.8	1.96	Clay
231	6 mi. W. 3 S. Texhoma	65.0	13.0	22.0	3.54	Sandy clay loam	63.8	15.6	20.6	3.85	Clay loam
236	7 mi. S. 5 W. Goodwell	60.2	14.0	25.8	2.87	Sandy clay loam	58.8	17.3	23.9	3.18	Sandy clay loam
241	6 mi. W. Texhoma	53.4	15.6	31.0	2.22	Sandy clay	59.0	12.4	28.6	2.49	Sandy clay loam
246	3 mi. W. Texhoma	48.2	23.0	28.8	2.47	Clay loam	49.2	23.0	27.8	2.59	Clay loam
281	8 mi. SW. Texhoma	62.2	12.8	25.0	3.00	Sandy clay loam	57.6	18.2	24.2	3.14	Sandy clay loam
286	21 mi. SW. Texhoma	58.2	11.0	30.8	2.24	Sandy clay	65.5	10.3	24.2	3.13	Sandy clay loam
291	23 mi. NE. Dumas, Tex.	29.4	19.7	50.9	0.96	Clay	29.8	18.0	52.2	0.91	Clay
296	5 mi. SW. Texhoma	52.4	19.8	27.8	2.59	Sandy clay loam	38.5	26.5	35.0	1.85	Clay
301	15 mi. SW. Texhoma	30.4	21.4	48.2	1 07	Clay	36.2	16.0	47.8	1.09	Clay
313	5 mi. S. Chamberlin, Tex.	49.6	18.2	32.2	2.10	Clay	45.0	18.0	37.0	1.70	Clay
318	6 mi. S. Chamberlin, Tex.	72.4	5.8	21.8	3.58	Sandy clay loam	71.0	11.0	18.0	4.55	Sandy loam
323	Eberle-SCS-P. Dalhart, Texas	58.8	11.8	29.4	2.40	Sandy clay loam	61.6	14.4	24.0	3.16	Sandy clay loam
328	4 mi. SW. Stratford, Tex.	51.8	24.0	24.2	3.13	Sandy clay loam	59.1	18.1	22.8	3.38	Sandy clay loam
340	3 mi. W. Conlin, Texas	76.8	5.0	18.2	4.49	Sandy loam	78.8	6.2	15.0	5.66	Sandy loam
345	4 mi. S. Conlin, Texas	65.6	14.6	19.8	4.05	Sandy loam	68.0	13.2	18.8	4.31	Sandy loam
350	1 mi. W. Conlin, Texas	66.0	14.0	20.0	4.00	Sandy clay loam	56.0	18.0	26.0	2.84	Sandy clay loam
355	Casey-SCS. P-Dalhart	82.0	8.0	10.0	9.00	Sand	85.4	7.4	7.2	12.88	Sand
361	1 mi. S. Chamberlin, Tex.	64.4	11.0	24.6	3.06	Sandy clay loam	70.8	7.4	21.8	3.58	Sandy clay loam
367	Peden-SCS-P-Dalhart	61.0	15.0	24.0	3.16	Sandy clay loam	56.4	12.4	31.2	2.20	Sandy clay
372	Casey-SCS-P-Dalhart	54.0	12.4	33.6	1.97	Sandy clay	53.4	17.6	29.0	2.44	Sandy clay loam
387	Pan. Agr. Exp. Sta	47.0	21.0	32.0	2.12	Clay	45.0	19.0	36.0	1.77	Clay
392	13 mi. W. Guymon	64.4	10.0	25.6	2.90	Sandy clay loam	64.4	10.4	25.2	2.96	Sandy clay loam
397	16 mi. SE. Elkhart, Kans.	70.8	7.6	21.6	3.62	Sandy clay loam	74.4	8.0	17.6	4.68	Sandy loam
402	5 mi. SE. Keyes	49.6	26.0	24.4	3.09	Clay loam	39.6	24.0	36.4	1.75	Clay
407	3 mi. S. 5 W. Keyes	60.6	18.4	21.0	3.76	Sandy clay loam	55.6	20.0	24.4	3.09	Sandy clay loam
412	4 mi. S. Campho, Colo.	71.6	13.0	15.4	5.49	Sandy loam	70.0	12.0	18.0	4.55	Sandy loam
417	16 mi. N. Boise City	43.2	20.8	36.0	1.77	Clay	41.0	24.0	35.0	1.85	Clay
421	3 mi. S. 9 E. Keyes	34.0	25.0	41.0	1.43	Clay	32.0	25.0	43.0	1.32	Clay
	Average	56.1	15.9	28.0	2.57		55.4	16.6	28.0	2.57	

*Based on Davis and Bennett's (2) classification.

both soils, which shows that there has been very little downward movement of the clay particles.

THE $\frac{\text{SAND} + \text{SILT}}{\text{CLAY}}$ RATIOS OF THE SOIL AND THE DRIFT

Since Bouyoucos (1) has suggested that the clay ratio may be used as a criterion of erosion, the ratio in the drift was compared with that of the adjacent cropped, virgin, and sub-surface soils. These ratios for the individual samples are recorded in Table 1 and the mean data for the three groups of soils in Table 2. The $\frac{\text{sand}+\text{silt}}{\text{clay}}$ ratios were found to be greater in the drift than either the cropped or the virgin soils, except in samples Nos. 79, 131, 178, 185, 245, and 391 which contained high percentages of clay under virgin conditions. The drift from all of these soils had over 20% clay and three were still classed as clays, two as sandy clay loams, and the other as a clay loam.

The sandy soils had the greatest ratios and the clay soils had the smallest, but the ratios in the drift were much higher than that in either the cropped, virgin, or sub-surface soils. The average ratio was 2.03 in the cropped, 1.89 in the virgin, 1.55 in the sub-surface, and 2.37 in the drift of the fine-textured soils, and 4.88 in the cropped, 5.53 in the virgin, 3.42 in the sub-surface, and 11.04 in the drift of the coarse-textured soils. The ratios in the drifts collected from the new dunes formed in 1935 varied from 1.85 to 6.35, while those in the drift that had been shifted at least four times varied from 9.41 to 49.00. The virgin surface soils of Nos. 366 and 371 were each sandy clay loams, containing 25% clay and had a clay ratio of 3.0, while the drift from the corresponding cropped soils contained only 3.0% and 2.0% clay, with clay ratios of 32.33 and 49.00, respectively.

Although the average drift had a wider clay ratio than the cropped or virgin soils, a study of these ratios in the individual samples seems to indicate that there was very little relation between this ratio and wind erosion. According to field observations, all types of soils eroded, at about the same rate, where there was no vegetation to protect the land. The fine-textured soils in many areas seemed to blow out to the plow depth, as shown in Fig. 4, about as readily as the sandy soils. However, after the compact clay subsoil was exposed, it resisted wind much better than the coarse-textured subsoils. Surface soil from 14 old lake beds were analyzed for sand, silt, and clay and the average clay ratio was 0.91, which is very low compared to the other soil of the region. Many areas of Randell clay, which is probably the finest textured soil in the panhandle of Oklahoma, have blown during the 1936 windy season. This soil seems to shift in granules or aggregates, while apparently there is a definite sorting out of the sand fraction in the coarse-, medium-, and most of the other fine-textured soils included in this study. Further studies are being made on the chemical analyses of these soils.

SUMMARY

The mechanical analyses of a large number of cropped and virgin surface and sub-surface soils of the southern high plains were determined and compared with the sand, silt, and clay contents of the soil drifts.

The greatest difference between drift material and the cropped and virgin surfaces occurred in the coarse- and medium-textured types. The drifts contained an average of 37.8% less silt and clay and 29.3% more sand than the adjacent virgin soil. It was also found that the increase in percentage of sand in the drifts was in proportion to the amount of silt and clay removed by the wind shifting the soil.

The $\frac{\text{sand}+\text{silt}}{\text{clay}}$ ratios in these soils were compared to that in the drifts. The drift from the coarse-textured soils had the highest clay ratios and the clay soils the lowest; however, the data reported seemed to indicate that there was very little relation between the clay ratio and wind erosion.

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A RAPID INDIRECT METHOD FOR DETERMINING THE WILTING COEFFICIENT OF SOILS[1]

GEORGE JOHN BOUYOUCOS[2]

ONE of the most important and significant characteristics of soils is their wilting coefficient, or the moisture content at which plants wilt. Because this characteristic is important and significant from both the scientific and practical standpoint, and because its direct determination is time consuming and rather difficult, considerable study has been made to discover an indirect, simple, and rapid method for its determination. Many schemes have been proposed and tried, but apparently they have proved unsuccessful. There seems to be one promising method, however, which was proposed by the author[3] as far back as 1916, but which never received the attention and consideration it deserved until recently. This method is the freezing point method.

In an intensive investigation of the freezing point depression of soil, it was discovered that when the moisture content of soil was reduced to a certain point the water would refuse to freeze or solidify when supercooled, whereas, before this minimum moisture content was reached, the water would very readily solidify when supercooled. The moisture content at which the water would refuse to solidify was different but quite definite for each type of soil. The idea was at once suggested that this critical water content at which solidification fails to take place may be the same as the water content at which plants wilt or the wilting coefficient of soils.

In order to obtain information upon this point, the wilting coefficient of several soils was determined at that time by following the method described by Briggs and Shantz and using wheat as an indicator. Table 1 contains a comparison of the results obtained in 1916 between the moisture content at which solidification failed to take place and the moisture content at which plants wilted.

It will be seen from the results in Table 1 that there is a very close agreement between the moisture content at which solidification fails to take place and the wilting point. It was concluded at that time that, "We confidently believe that the point where solidification refuses to take place marks an important transition in the state of the soil moisture and that this point is very close to the wilting coefficient of soils. Hence, we further believe that the freezing point method can be used to determine the wilting coefficient of soils and that such determinations will be more accurate and of course infinitely more convenient and rapid."

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[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Authorized for publication by the Director as Journal Article No. 265, n. s., of the Michigan Agricultural Experiment Station. Received for publication April 29, 1936.

[2]Research Professor in Soils.

[3]BOUYOUCOS, G. J., and MCCOOL, M. M. Further studies on the freezing point lowering of soils. Mich. Agr. Exp. Sta. Tech. Bul. 31:1–51. 1916.

TABLE 1.—*Comparison of the moisture content of soils at which solidification fails to take place and at which plants wilt.*

Soils	Percentage of water at which solidification fails to take place	Percentage of water at which plants wilt
Sand	2.10	1.49
Sandy loam	6.70	5.28
Silt loam	10.3	9.62
Heavy silt loam	16.8	18.79
Heavy silt loam	13.50	13.82
Sandy loam	5.00	4.87

IMPROVED PROCEDURE

The freezing point method as a possible indirect rapid method for determining the wilting point of soils has received further investigation and the procedure finally adopted for obtaining the critical moisture at which solidification fails to take place, and which in turn is the wilting point, is as follows: The soil to be studied is first passed through a 2-mm sieve and thoroughly mixed. Exactly 20 grams of this air-dry soil is weighed out carefully. About half of this amount is poured into a freezing tube (1 inch inside diameter and 9 inches long). By means of a very narrow 5-cc burrette graduated into 0.1 cc a definite amount of distilled water is added to the soil. The other half of the soil is then poured into the tube so that the water is between the two layers of soil. The tube is stoppered and allowed to stand. This procedure is repeated until four or five samples of any given soil are thus prepared, varying in water content by exactly 0.5 cc. The moisture content at which solidification fails to take place is so low that the soil is barely moist, breaks up into granules, and exhibits no stickiness. In wetting the soil samples, therefore, one has to wet them just enough so that their water content falls around the critical point. With a little experience, one easily learns not to use too high or too low water contents in preparing the soil samples.

After the soils have stood in the tubes for a few hours so that the water is absorbed, each sample is thoroughly mixed by means of an iron rod flattened at the point, and also by inverting and rotating the tubes after the soils have been reduced to granules by the rod. Any soil sticking to the rod is scraped off into the tube by a small spatula. Those samples having the highest moisture contents and in which the water has penetrated the entire mass are not mixed by the rod but left undisturbed. By following this procedure of wetting the soil samples, there is no loss of water taking place, and consequently the results are more accurate.

After the soils are mixed with the rod they are allowed to stand about half an hour longer in order that the water may become better distributed throughout the soil mass. Their freezing point depression is then determined by inserting the bulb of a Beckmann thermometer into the soil column in the tube and placing the tube directly in a cooling mixture having a temperature of about —2.5° C. After the

soil is supercooled to about 0.8° C below its estimated freezing point, the tube is taken out, wiped dry quickly, placed into the air jacket of the cooling bath, and solidification is started by moving the thermometer around in the soil. The temperature is allowed to rise with frequent tapping of the thermometer until the mercury column comes to a standstill when its height is read and recorded.

Solidification starts always very easily when the soils are supercooled to about 0.8° C below their freezing point, until the critical moisture content is reached. It is very easy to recognize this critical point in the following ways: (a) By the great difficulty in starting solidification; (b) if solidification starts after vigorous stirring, the temperature rises only a little then falls again; and (c) the freezing point depression jumps up tremendously from the preceding one. For instance, if the FPD is 1.300° C and then jumps to 2.500° C following a reduction of 2.5% in moisture content, the critical point is about reached.

Care must be taken that the cooling mixture is not much colder than —2.5° C, otherwise premature solidification is likely to occur. For the same reason, when the soil is placed in the cooling mixture it must not be disturbed until it is removed into the air jacket. If for any reason premature solidification has taken place the soil should be warmed and mixed over again with the rod.

In Table 2 are presented some typical experimental results obtained according to the procedure described above in order to show the relationship between the freezing point depression and the moisture content and the critical moisture content where solidification fails to take place and consequently no freezing point determination can be made. The total moisture content of each soil contains also the hygroscopic moisture.

One of the most striking things revealed by the results given in Table 2 is the extreme sensitiveness of the freezing point depression as the moisture content decreases. At the higher moisture contents a decrease of 5% moisture may cause an increase of only 0.012° C in the freezing point depression, but at the lower moisture contents and especially near the critical water content where solidification fails to take place, a decrease of only 2.5% moisture may cause an increase of more than 1.00° C in the freezing point depression.

This extreme sensitiveness of the freezing point depression to the water content at the lower moisture contents is of great practical importance for it makes possible the determination of the wilting coefficient by the freezing point method with an accuracy of about 1 to 2%. It will be seen that the difference in the moisture content between the points where a freezing point determination can and cannot be made is only 2.5%. By estimation this amount can be reduced to about 1% which would represent a very high accuracy in determining the wilting point indirectly and rapidly.

It must be further observed from the results in Table 2 that since small variations in moisture content produce great variations in the freezing point depression near the critical moisture content, then this critical water content where solidification refuses to take place be-

TABLE 2.—*Showing the behavior of the freezing point depression of soils as the moisture content is decreased and the critical moisture content at which freezing point determinations cannot be made.*

Water added, cc	Total moisture %	Freezing point depression, C°
	Buchner Silt Loam Surface	
6.0	33.0	0.090
5.0	28.0	0.110
4.0	23.0	0.280
3.5	20.5	0.490
3.0	18.0	0.710
2.5	15.5	0.935
2.0	13.0	1.450
1.5	10.5	No solidification
	La Moure Silty Clay Surface	
9.0	50.0	0.130
8.0	45.0	0.150
7.0	40.0	0.170
6.5	37.5	0.185
6.0	35.0	0.220
5.5	32.5	0.226
5.0	30.0	0.350
4.5	27.5	0.435
4.0	25.0	0.635
3.5	22.5	0.965
3.0	20.0	1.345
2.5	18.5	No solidification
	Hagerstown Silt Loam Subsoil	
7.0	39.0	0.028
6.0	34.0	0.045
5.0	29.0	0.060
4.0	24.0	0.135
3.5	21.5	0.215
3.0	19.0	0.375
2.5	16.5	0.585
2.0	14.0	1.180
1.5	11.5	No solidification
	Davidson Clay Loam Subsoil	
8.0	42.0	0.055
7.0	37.0	0.125
6.0	32.0	0.222
5.5	29.5	0.320
5.0	27.0	0.545
4.5	24.5	1.035
4.0	22.0	1.725
3.5	19.5	No solidification

comes rather definite and reliable as a criterion of the wilting coefficient of soils.

In performing the experiments reported in Table 2, as well as numerous other experiments, it was found that the maximum degree of depression of the freezing point that could be reliably measured in normal or non-alkalie soils at the lowest moisture content at which solidification would still take place tended to be about 1.40° C. Greater freezing point depressions than this would not be true or re-

liable. This figure of 1.40° C is very significant for it has a bearing upon the validity of the proposed freezing point method for determining the wilting coefficient, as will be shown subsequently in this paper.

A thorough consideration reveals no fundamental reason why the moisture content at which solidification fails to take place could not be the same as that at which plants wilt because both phenomena seem to represent the same critical equilibrium point. The wilting coefficient, for instance, represents a definite and fundamental equilibrium between the pulling forces of the plant and of the soil for water. At the wilting coefficient the pulling forces of the soil for the water commence to exceed those of the plant and consequently the plant wilts because it cannot withdraw water from the soil. In a similar manner, the moisture content at which solidification refuses to take place also represents a definite and fundamental equilibrium between the pulling forces of the soil and the forces of crystalization for the water. When the pulling forces of the soil for the water begin to predominate or exceed the forces of crystalization, then the water cannot be made to solidify, at least not very readily. Hence, both the wilting coefficient and the non-solidification point seem to represent the same soil-moisture equilibrium point.

It was mentioned above that, although the freezing point method was suggested 20 years ago as a rapid indirect method for determining the wilting coefficient, it is only in the last year or so that the method has received attention and confirmation from other workers. The strongest confirmation of the method comes from the work of Veihmeyer.[4] Veihmeyer has for many years been conducting a very intensive and thorough investigation on the wilting coefficient of soils using many types of soils and many different plants. He has found that all plants tend to wilt at the same moisture content for any given soil and that at the wilting point the soils tend to have a freezing point depression of about 1.40° C, which is equal to an osmotic pressure of about 16 atmospheres.

This finding of Veihmeyer is entirely in agreement with the finding already presented in this paper showing that at slightly above the critical moisture content where solidification fails to take place, the freezing point depression tends to be about 1.40° C. This finding of Veihmeyer, therefore, constitutes a strong confirmation to the proposed freezing point method for determining the wilting coefficient.

The second confirmation of the method comes from some researches by Schofield and Botelho Da Costa[5], who found the freezing point method a very practical means of determining the wilting coefficient and moisture equivalent of soils.

All the various evidences go to show, therefore, that the freezing point method can be employed as a rapid, indirect method to determine the wilting coefficient of soils with reasonable accuracy.

[4]VEIHMEYER, F. J. Some measurements of the availability of water to plants. Paper read at the annual meeting of the American Society of Agronomy, Chicago, Ill., December 6, 1935.

[5]SCHOFIELD, R. K., and BOTELHO DA COSTA, J. V. ————, ————. Trans. 3d Intern. Congress Soil Sci., I. Commission Papers. 1935.

In a subsequent report it will be shown that the dilatometer can also be used as a very rapid and accurate method to determine the wilting coefficient of soils.

SUMMARY

Evidence is presented showing that the freezing point method can be used as an indirect method to determine rapidly the wilting coefficient of soils with reasonable accuracy.

AGRONOMIC AFFAIRS

NEWS ITEMS

DR. C. E. MARSHALL of the University of Leeds, England, has accepted appointment as Visiting Professor in the Department of Soils at the University of Missouri for the coming university year. He will temporarily occupy the position held by Dr. Hans Jenny, who has accepted appointment at the University of California at Berkeley. Dr. Marshall's work on soil colloids, particularly that having to do with base exchange and the optical properties of clays, is well known throughout the United States and Europe. While at the University of Missouri he is expecting to give special attention to the optical properties and mineralogical makeup of American clays and their relationships to colloid chemical phenomena, such as base exchange, stability, and coagulation. This work should be of interest, not only in its fundamental aspects, but in its application to certain specific problems on which the Missouri Experiment Station has been working, such as those concerned with soil genesis, plant nutrition, the rôle of calcium in nitrogen fixation, and the influence of exchangeable bases on the ecological relationships of pastures.

R. J. GARBER has resigned as head of the Department of Agronomy and Genetics of West Virginia University to become a principal agronomist in the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. He will be Director of the Regional Laboratory for Pasture Research in the Northeastern States. Headquarters have been established at the Pennsylvania State College of Agriculture, State College, Pa.

DR. J. N. HARPER, for many years identified with soil fertility problems in the South, died at his home in Atlanta, Georgia, on July 1.

C. W. DOXTATOR, Instructor in Agronomy and Plant Genetics, University of Minnesota, has resigned from his position effective August 1 to accept a position with the American Beet Sugar Company with headquarters at Rocky Ford, Colorado. On July 1, Dean C. Anderson of the Colorado Experiment Station was appointed to take the place vacated by Mr. Doxtator. Other new assistants in the Division are Royse P. Murphy and David Reid, graduates of Kansas State College, and Henry A. Johnson, graduate of the University of Minnesota.

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THE EFFECT OF WIND EROSION AND CULTIVATION ON THE TOTAL NITROGEN AND ORGANIC MATTER CONTENT OF SOILS IN THE SOUTHERN HIGH PLAINS[1]

HARLEY A. DANIEL AND WRIGHT H. LANGHAM[2]

SINCE wind erosion is a serious agricultural problem in many parts of the southern high plains, information concerning the change in total nitrogen and organic matter content of soils as affected by wind erosion and cropping is important. Middleton, Slater and Byers (4, 5)[3] studied the effect of water erosion on the chemical composition of soils and found that the greatest decrease in fertility due to the removal of the surface soil by erosion was the loss of nitrogen and organic matter.

Moss (6) found that soils in Canada which had been drifted by wind had a lower hygroscopic coefficient and the loss on ignition and the total nitrogen and phosphorus content was less than undrifted coarse-textured soils, while comparisons between drifted areas and undisturbed fine-textured soils were almost identical. Fly (3) compared the chemical composition of dust deposited in buildings at Goodwell, Oklahoma, with Richfield silt loam soil and found that the dust contained about twice as much available plant nutrients as the soil. Murphy (7) also found that dust which settled in Central Oklahoma after the storms in the high plains in March and April of 1935 was high in organic matter.

EXPERIMENTAL PROCEDURE

Composite samples of cropped, virgin, and drifted soils were collected in or near the Oklahoma Panhandle during the fall and winter of 1935–36. The different samples were taken as close together as possible and in all cases within 100

[1]Contribution from the Oklahoma Agricultural Experiment Station, Stillwater, Okla. The research was conducted at the Panhandle Agricultural Experiment Station, Goodwell, Okla. Published with the permission of the Director of the Oklahoma Agricultural Experiment Station. Received for publication April 25, 1936.

[2]Assistant Agronomist and acting Director of the Panhandle Experiment Station and Chemist of the Panhandle Station, respectively. The authors wish to express their appreciation to Frank T. Ellsaesser, George A. Dysinger, and Clyde H. Jamison, student assistants, for assisting with the laboratory work.

[3]Figures in parenthesis refer to "Literature Cited", p. 596.

yards of each other. The surface samples were secured at a depth varying from 0 to 12 inches and the subsurface soils from 12 to 18 inches. The samples of drift were collected from hummocks and sand dunes that formed along fences or around stationary objects. Several profiles were also taken from representative soils in the area.

These soils were air dried and analyzed for total nitrogen by a method recommended by the Association of Official Agricultural Chemists and for organic matter by the Schollenberger (8) chromic acid method.

RESULTS

PERCENTAGE OF ORGANIC MATTER AND NITROGEN IN SOILS AS AFFECTED BY WIND EROSION

All of the surface soils which were studied were classified into three groups based on the percentage of sand, silt, and clay which they contained and the results of the chemical analyses are given in Table 1. Although a considerable variation occurred between individual samples, the medium and fine-textured soils, as a whole, contained more organic matter and nitrogen than the sandy soils.

The mean percentage of organic matter and nitrogen in the different soils were recorded in Table 2. The drifted material had an average of 24.5% less organic matter and 28.0% less nitrogen than samples obtained from virgin areas. Some of the drifts on the medium and fine-textured land, however, contained higher percentages of these constituents than either the cropped or virgin soils. The drifts from nine areas of land that had shifted at least four times averaged 52.2% less organic matter and 56.8% less nitrogen than the virgin surface, while samples collected from five newly formed dunes after the first dust storms in 1936 were decreased only 10.0% in nitrogen and 11.7% in organic matter. Soil 371, a sandy clay loam, had 0.117% nitrogen in the cropped surface and the percentage of this element in the drift was only 0.020. These results suggest that each time a soil is shifted some organic matter and also a portion of the silt and clay are removed, and as the process continues the dune from soils that are dispersed by the wind finally becomes sand (Fig. 1), regardless of the original texture. Data shown in Table 3 more clearly emphasize the importance of fertility losses due to wind erosion. The sand dunes averaged 49.7% less organic matter and 53.9% less nitrogen than the undrifted soil. The decrease was not as great in drifts derived from soils containing higher percentages of silt and clay.

Several of the drifted soils had a higher percentage of organic matter than the undrifted. A large amount of undecomposed vegetation, as shown in Fig. 2, frequently accumulated in some drifts and the chromic acid oxidized this material, which apparently explains why these ratios were higher in the drift. In some instances drifts from the fine-textured soils that had not moved for 2 years were considerably higher in both organic matter and nitrogen. Such a condition seemed to exist only in drifts from virgin soil or from cultivated fields that had large quantities of undecomposed plant material. It is quite probable that the grinding effect of moving sand on large masses of undecomposed residues reduces them to

fine powder and that, combined with decay, the losses of organic matter are high with each movement of soil. Even if drifts did

FIG. 1.—A very destructive effect of wind erosion on virgin sandy loam soil.

contain more of plant nutrients due to the inclusion of undecomposed residues, the humus which forms in the process of decay was transferred from some productive area. The average ratio of organic

FIG. 2.—Undecomposed residues accumulated in a hummock.

TABLE 1.—*The total nitrogen and organic matter content of cropped, virgin, and drifted soils in the southern high plains.*

Sample No.	Place collected	Virgin surface			Cropped surface			Soil drift		
		Class*	O.M., %	N, %	Class*	O.M., %	N, %	Class*	O.M., %	N, %
					Coarse-textured Soils*					
42	3 mi. S. Goodwell	Sandy loam	2.62	0.149	Sandy clay loam	1.95	0.145	Sand	0.82	0.032
63	10 mi. N. Goodwell	Sandy loam	1.32	0.051	Sandy loam	1.88	0.080	Sand	1.02	0.033
75	4 mi. N. W. Hooker	Sandy loam	2.49	0.114	Sandy loam	1.51	0.060	Sandy loam	2.17	0.089
106	10 mi. E. Turpin	Sandy loam	2.21	0.089	Sandy loam	1.41	0.060	Sand	1.25	0.041
111	6 mi. S. Turpin	Sandy loam	1.31	0.031	Sandy loam	1.16	0.053	Sand	0.65	0.021
115	4 mi. S. Turpin	Sandy loam	2.10	0.086	Sandy clay loam	1.65	0.068	Sandy loam	1.64	0.064
127	6 mi. S. Beaver	Sandy loam	2.02	0.092	Sandy loam	1.43	0.071	Sand	0.59	0.023
151	11 mi. N. Goodwell	Sandy loam	1.80	0.074	Sand	1.07	0.040	Sand	1.01	0.037
155	12 mi. N. Goodwell	Sandy loam	2.15	0.081	Sand	0.73	0.044	Sand†	0.22	0.024
170	1 mi. E. Hooker	Sandy loam	1.61	0.067	Sandy clay loam	1.81	0.071	Sandy loam	1.46	0.051
174	2 mi. N. E. Tyrone	Sandy loam	1.32	0.050	Sandy loam	1.49	0.050	Sand	0.91	0.023
230	6 mi. W. 3 S. Texhoma	Sandy loam	1.81	0.078	Sandy loam	1.57	0.071	Sand	0.75	0.029
240	6 mi. W. Texhoma	Sandy loam	1.71	0.081	Sandy loam	2.02	0.068	Sand	0.75	0.036
285	21 mi. S. W. Texhoma	Sandy loam	2.10	0.086	Sandy clay loam	1.75	0.080	Sandy loam	1.52	0.059
317	6 mi. S. Chamberlin, Tex.	Sandy loam	1.25	0.058	Sandy loam	1.25	0.057	Sand†	1.17	0.036
322	Eberle–SCS–P–Dalhart	Sandy loam	2.23	0.086	Sandy clay loam	1.62	0.074	Sand†	0.96	0.033
334	6 mi. S. W. Conlin, Texas	Sandy loam	1.98	0.087	Sandy clay	1.55	0.082	Sandy loam†	1.68	0.064
339	3 mi. W. Conlin, Texas	Sand	1.49	0.057	Sandy loam	1.53	0.052	Sand	1.67	0.063
344	4 mi. S. Conlin, Texas	Sand	1.25	0.045	Sandy loam	1.62	0.067	Sand†	0.79	0.020
349	1 mi. W. Conlin, Texas	Sandy loam	1.92	0.082	Sandy loam	1.86	0.072	Sand	0.92	0.046
354	Casey–SCS–P. Dalhart, Tex.	Sand	1.07	0.037	Sand	1.07	0.036	Sand†	0.86	0.031
360	1 mi. S. Chamberlin, Texas	Sand	1.61	0.074	Sandy loam	1.50	0.071	Sand†	0.57	0.021
396	16 mi. S. E. Elkhart, Kansas	Sandy loam	1.81	0.060	Sandy loam	1.72	0.064	Sand‡	1.17	0.048
411	4 mi. S. Campho, Colorado	Sand	1.30	0.044	Sand	1.13	0.038	Sand	0.82	0.026
					Medium-textured Soils*					
59	4 mi. E. 2 N. Goodwell	Sandy clay loam	2.74	0.114	Sandy loam	1.66	0.075	Sandy loam	3.10	0.122
71	2 mi. N. 3 E. Mouser	Sandy clay loam	2.16	0.089	Sandy clay loam	1.84	0.074	Sandy loam	0.97	0.032
79	2 mi. N. Hooker	Clay loam	3.14	0.125	Sandy clay loam	1.85	0.080	Clay loam	2.65	0.119
87	3 mi. E. Optima	Sandy clay loam	2.31	0.095	Sandy loam	1.78	0.085	Sand	1.53	0.060
96	14 mi. E. Guymon	Clay loam	3.27	0.140	Clay loam	1.93	0.092	Clay loam	3.75	0.164
102	18 mi. E. Hardesty	Clay loam	3.51	0.156	Clay loam	1.80	0.080	Sandy loam	2.45	0.113

123	2 mi. S. E. Forgan	Sandy clay loam	2.68	0.120	Sandy clay loam	2.58	0.122	Sandy loam	1.70	0.089
131	20 mi. S. Beaver	Clay loam	3.71	0.155	Clay	2.38	0.114	Clay	3.75	0.146
147	½ mi. W. Goodwell	Clay loam	2.22	0.094	Clay	2.15	0.092	Sandy clay loam	1.25	0.053
162	10 mi. N. Guymon	Sandy clay loam	2.75	0.125	Sandy clay loam	2.82	0.139	Sandy clay loam	3.55	0.144
215	6 mi. S. 4 W. Goodwell	Sandy clay loam	2.52	0.098	Sandy clay loam	1.75	0.072	Sand	1.17	0.047
225	4 mi. S. Goodwell	Clay loam	2.77	0.150	Clay loam	2.62	0.121	Sandy clay loam	1.92	0.086
235	7 mi. S. Goodwell	Sandy clay loam	2.17	0.081	Sandy clay loam	2.05	0.088	Sandy clay loam	2.90	0.109
245	3 mi. W. Texhoma	Clay loam	3.60	0.161	Sandy clay loam	2.77	0.108	Sandy clay loam	2.37	0.110
280	8 mi. S. Texhoma	Sandy clay loam	2.66	0.102	Sandy loam	1.77	0.066	Sandy loam	3.72	0.141
290	23 mi. N. E. Dumas, Texas	Clay loam	2.38	0.102	Clay loam	2.22	0.096	Sandy loam	2.17	0.085
295	5 mi. S. W. Texhoma	Clay loam	2.85	0.088	Sandy clay loam	2.22	0.105	Sand	1.37	0.045
300	15 mi. S. W. Texhoma	Clay loam	2.09	0.103	Clay loam	1.95	0.096	Sandy loam	1.77	0.061
305	3 mi. W. 1 S. Texhoma	Clay loam	1.72	0.083	Sandy clay loam	2.00	0.081	Sandy loam	2.59	0.105
312	5 mi. S. Chamberlin, Tex	Clay loam	2.15	0.101	Sandy clay	2.54	0.101	Sandy clay loam	1.85	0.076
327	4 mi. S. W. Stratford, Tex	Sandy clay loam	2.82	0.108	Clay	1.26	0.074	Sandy loam	1.71	0.070
366	Peden–SCS–P–Dalhart, Tex	Sandy clay loam	2.62	0.102	Sandy loam	2.47	0.101	Sand†	1.00	0.044
371	Casey–SCS–P–Dalhart, Tex	Sandy clay loam	2.25	0.098	Sandy clay loam	2.67	0.117	Sand†	0.58	0.020
391	13 mi. W. Guymon	Sandy clay loam	2.36	0.103	Sandy clay loam	2.47	0.099	Sandy clay loam‡	2.89	0.124
406	3 mi. S. 5 W. Keyes	Sandy clay loam	1.92	0.090	Sandy loam	1.45	0.066	Sand	0.90	0.030
416	16 mi. N. Boise City	Sandy clay loam	2.66	0.137	Sandy clay loam	1.80	0.086	Sandy loam‡	1.25	0.062
				Fine-textured Soils*						
46	5 mi. S. 2 E. Goodwell	Clay	2.21	0.147	Sandy clay loam	2.27	0.094	Sandy clay loam	1.97	0.075
67	1 mi. S. E. Hough	Clay	2.82	0.129	Clay	2.08	0.101	Clay loam	4.10	0.165
92	4 mi. E. Guymon	Clay	2.80	0.101	Clay	1.72	0.082	Sandy clay	1.72	0.062
140	1 mi. W. Farnsworth, Texas	Clay	3.15	0.133	Clay	2.70	0.125	Clay	3.23	0.136
166	4 mi. W. 1½ N. Goodwell	Clay	3.84	0.172	Clay	2.55	0.112	Clay loam	2.47	0.114
178	3 mi. W. 2 N. Goodwell	Clay	3.32	0.153	Clay	2.52	0.131	Clay	2.50	0.117
185	3 mi. N. 1 W. Goodwell	Clay	2.48	0.124	Clay	2.56	0.124	Clay	2.40	0.115
220	6 mi. S. 1 W. Goodwell	Clay	4.17	0.159	Clay	2.87	0.133	Sandy clay loam	2.47	0.102
386	Pan. Agr. Exp. Sta. Goodwell	Clay	2.87	0.108	Clay loam	2.05	0.094	Sandy clay loam‡	2.70	0.109
402	5 mi. S. E. Keyes	Clay	2.43	0.117	Clay	2.35	0.112	Sandy clay loam	1.65	0.079
421	3 mi. S. 9 E. Keyes	Clay	1.80	0.094	Clay	1.97	0.105	Clay‡	2.12	0.109

*Based on the mechanical analyses reported on these soils by Daniel (1). Virgin surface used as base for classification, coarse-textured soils 20% clay or less, medium textured soils 20 to 30% clay, and fine-textured soils over 30% clay.
†Samples collected from dunes that have been shifted at least four times.
‡Samples collected from new dunes formed during the first dust storms of 1936.

TABLE 2.—*The mean total nitrogen and organic matter content of cropped, virgin, and drifted soils and the ratios between these constituents in these soils.*

Kind of soil	No. of samples analyzed	Organic matter Soil, %	Organic matter Difference, %*	Nitrogen Soil, %	Nitrogen Difference, %*	Organic matter-nitrogen ratio
		Coarse-textured Soils†				
Virgin surface . .	24	1.77	——	0.073	——	24.25
Cropped surface	24	1.51	—14.7	0.066	—9.6	22.88
Drifted soils. . . .	24	1.06	—40.1	0.040	—45.2	26.50
		Medium-textured Soils†				
Virgin surface . .	26	2.62	——	0.112	——	23.39
Cropped surface	26	2.11	—19.5	0.093	—17.0	22.69
Drifted soils. . .	26	2.11	—19.5	0.087	—22.3	24.25
		Fine-textured Soils†				
Virgin surface . .	11	2.90	——	0.131	——	22.14
Cropped surface	11	2.33	—19.7	0.110	—16.0	21.18
Drifted soils. . . .	11	2.48	—14.5	0.107	—18.3	23.18
		Average of All Soils				
Virgin surface . .	61	2.33	——	0.100	——	23.30
Cropped surface	61	1.91	—18.0	0.085	—15.0	22.47
Drifted soils. . . .	61	1.76	—24.5	0.072	—28.0	24.44

*Virgin soil used as standard.
†Coarse-textured soils, virgin surface 20% clay or less, medium-textured soils 20 to 30% clay, and fine-textured soils over 30% clay (1).

TABLE 3.—*The composition of the drifted and virgin soils classified according to the texture of the remaining dunes*

Texture of drifted soils	Number of samples analyzed	Virgin surface O. M., %	Virgin surface N, %	Drifted soil O. M., %	Drifted soil N, %	Difference between drifted and virgin soil* O. M., %	Difference between drifted and virgin soil* N, %
Sand	25	1.87	0.076	0.94	0.035	—49.7	—53.9
Sandy loam. . . .	15	2.38	0.104	1.99	0.080	—16.4	—23.1
Sandy clay loam and clays.	21	2.86	0.127	2.58	0.110	—9.8	—13.4

*Virgin surface used as standard.

matter to nitrogen in the cropped soil was 22.47 and that in the virgin 23.30, while the average in the drifts was 24.44. The drift from each group had a higher ratio of organic matter to nitrogen than the soil. Since there were greater losses of nitrogen than organic matter, it appears that the fine humus, or the most valuable part of the soil, has disappeared. As previously stated, the authors (1) do not mean to say that all the organic matter and nitrogen removed from the soil by wind erosion left the country due to the settling of the dust in adjacent areas. But a large amount of plant nutrients must have been carried away from the high plains since the deposition of dust has been reported throughout a large part of the United States.

Some of the farmers in the high plains seem to have the opinion that wind erosion has not damaged their land. In order to stress the importance of reducing the harmful effect of wind erosion, data are presented in Table 4 which show that the nitrogen and organic matter content of the subsurface layers is much lower than that of the surface soil. These samples were taken from typical areas of land and it should not be difficult to recognize the damage which occurs when the surface soil is removed by wind erosion, especially on shallow areas similar to the Potter series. A large number of drifted soils have already lost over 50% of their original organic matter and the results of analyses support the suggestion (1) that many areas in the high plains may eventually become bare caliche or dunes of drifting sand (Fig. 1) with no agricultural value, if wind erosion is not controlled.

ORGANIC MATTER AND NITROGEN CONTENT OF CROPPED AND VIRGIN SOILS

Due to the large amount of surface movement of soil that has taken place, it was difficult to find representative areas from which accurate samples of soils could be obtained. In many areas several inches of dust had accumulated on the surface of virgin soils, but this deposited material was removed and the sample was taken from the old sod. Since much of the surface soil has been removed from some cultivated fields, many of these samples represent losses which are due entirely to wind erosion. Although some of the cultivated soils contained higher percentages of plant nutrients than the virgin soils, the average loss of organic matter was 18% and the nitrogen loss 15%. The greatest decrease in the percentage of organic matter and nitrogen occurred in the medium and fine-textured soils. In addition to these losses, the prolonged drouth, accompanied by crop failure and over-grazing, has destroyed the vegetative covering, leaving the soil exposed to the action of the wind.

In many places at the present time it is very difficult to determine whether the land is cropped or virgin soil. In such cases soils from adjacent cultivated fields have blown over the native sod killing the grass and in a short while such land starts blowing as badly as the cropped field, as shown in Fig. 1. This particular sandy loam soil has been denuded to a depth of 4 or 5 feet, leaving a sand dune with very little plant nutrients. Samples were taken from a similar area northwest of Dalhart, Texas, where the shifting sand has destroyed about two sections of land. It was found that these dunes had 75.5% less nitrogen than the undrifted soils, the percentages being 0.012 and 0.049, respectively. Some of these dunes are 10 to 15 feet high and are constantly shifting, due to the absence of vegetative cover.

Subsurface soils were collected from 32 areas of virgin and cropped land in various parts of the southern high plains and analyzed for organic matter and total nitrogen. There was a wide variation in the composition of individual samples, but the data in Table 5 show that the virgin subsurface was only slightly higher in these constituents than the subsurface soil in cultivated fields. Since these soils have

TABLE 4.—*The organic matter and nitrogen content of some soil profiles in Texas County, Okla.*

Sample No.	Soil type*	1st foot		2nd foot		3rd foot		4th foot		5th foot		6th foot	
		O. M., %	N, %	O. M., %	N, %	O. M., %	N, %	O. M., %	N, %	O. M., %	N, %	O. M., %	N, %
209	Richfield silt loam.....	1.25	0.061	1.02	0.054	0.80	0.047	0.80	0.040	0.71	0.039	0.60	0.032
256	Richfield silt loam .. .	2.15	0.093	1.77	0.086	1.11	0.053	0.82	0.031	0.52	0.016	0.42	0.014
274	Richfield silt loam ...	1.61	0.087	1.10	0 066	0.85	0.040	0.47	0.038	0.42	0.031	0.40	0.020
268	Richfield clay..	2.02	0.102	1.50	0.064	0.75	0.047	0.67	0.036	0.67	0.028	0.45	0.019
250	Pratt fine sandy loam .	1 99	0.089	1.30	0.063	1.02	0.046	0.72	0.040	0.70	0.036	0.50	0.025
195	Pratt fine sandy loam	3.37	0.139	2.18	0 113	1.07	0.059	0.67	0.027	Caliche		—	—
199	Potter fine sandy loam.	1.34	0.047	0.64	0.017	0.48	0.011	0.33	0.007	Caliche		—	—
203	Potter silt loam . .	3.02	0.140	1.13	0 047	0.65	0.024	Caliche		—	—	—	—
	Average .. .	2.09	0.095	1.29	0 064	0 84	0.041	0.64	0 031	0.60	0.030	0.47	0.022

*According to Texas County soil map by Fitzpatrick and Boatright (2).

been in cultivation for a relatively short period of time and since the major portion of the roots of cultivated crops develop in the surface foot of soil, very little change in the nitrogen content of the subsurface layer has occurred. The texture of the subsurface soil is not unfavorable for cultivation where the caliche is not too near the surface and the quantity of total nitrogen and organic matter is about equal to that which occurs on the cropped surface at the present time. Further studies are being made on the mineral analyses of these soils.

TABLE 5.—*The total nitrogen and organic matter content of cropped and virgin subsurface soils in the Panhandle.*

Sample No.	Place collected	Cropped subsurface		Virgin subsurface	
		O. M., %	N, %	O. M., %	N, %
216	6 mi. S. 4 W. Goodwell, Okla.	1.80	0.085	2.30	0.099
221	6 mi. S. 1 W. Goodwell, Okla	2.57	0.110	2.97	0.125
226	4 mi. S. W. Goodwell, Okla.	2.80	0.133	2.92	0.147
231	6 mi. W. 3 S. Texhoma, Okla	1.75	0.080	1.90	0.086
236	7 mi. S. 5 W. Goodwell, Okla.	1.75	0.080	1.75	0.074
241	6 mi. W. Texhoma, Okla	1.75	0.083	1.76	0.080
246	3 mi. W. Texhoma, Okla	1.97	0.101	2.45	0.127
281	8 mi. S. W. Texhoma, Okla.	1.64	0.068	1.62	0.066
291	23 mi. N. E. Dumas, Texas	1.95	0.105	2.10	0.092
296	5 mi. S. W. Texhoma, Okla.	1.65	0.090	2.10	0.085
301	15 mi. S W. Texhoma, Okla	1.82	0.092	1.80	0.105
313	5 mi. S. Chamberlin, Texas	1.77	0.075	1.27	0.065
318	6 mi. S. Chamberlin, Texas.	1.22	0.060	1.37	0.048
323	Eberle–SCS–P. Dalhart, Texas.	1.40	0.061	1.30	0.074
328	4 mi. S. W. Stratford, Texas.	1.97	0.089	1.95	0.086
340	3 mi. W. Conlin, Texas	1.50	0.057	1.20	0.052
345	4 mi. S. Conlin, Texas	1.57	0.072	1.60	0.064
350	1 mi. W. Conlin, Texas	1.45	0.064	1.74	0.050
355	Casey–SCS–P. Dalhart, Texas.	1.22	0.057	1.15	0.044
361	1 mi. S. Chamberlin, Texas.	1.42	0.068	1.57	0.071
367	Peden–SCS–P. Dalhart, Texas.	1.92	0.091	1.73	0.086
372	Casey–SCS–P. Dalhart, Texas	2.22	0.105	1.74	0.075
387	Pan. Agr. Exp. Sta. Goodwell, Okla.	1.57	0.082	2.25	0.093
392	13 mi. W. Guymon, Okla	2.11	0.104	2.35	0.104
397	16 mi. S. E. Elkhart, Kan.	1.49	0.064	1.39	0.060
402	5 mi. S. E. Keyes, Okla	2.17	0.107	1.97	0.096
407	3 mi. S. 5 W. Keyes, Okla.	1.41	0.062	1.85	0.075
412	4 mi. S. Campho, Colo.	1.25	0.064	2.00	0.096
417	16 mi. N. Boise City.	1.87	0.107	1.89	0.100
422	3 mi. S. 9 E. Keyes, Okla.	1.25	0.080	1.96	0.098
286	21 mi. S. W. Texhoma, Okla.	1.92	0.077	2.00	0.073
306	3 mi. W. 1 S. Texhoma, Okla.	1.67	0.071	1.59	0.083
	Average	1.74	0.083	1.86	0.084
	Average of surface soils*	1.91	0.085	2.33	0.100

*Data obtained from Table 2.

SUMMARY

The total nitrogen and organic matter content was determined in cropped, virgin, and drifted soils of the southern high plains. The drift had an average of 24.5% less organic matter and 28.0% less nitrogen than the virgin soil.

The data indicate that each time a soil is shifted more plant nutrients are removed, and that after being moved a large number of times, the dunes from soils that are dispersed by the wind finally became sand, regardless of the original texture. The organic matter-nitrogen ratios were determined and it was found that this ratio in the cropped soil was 22.47 and that in the virgin 23.30, while the average of the drifts was 24.44.

Since the total nitrogen and organic matter in the soil profile decreases rapidly with depth, the data clearly prove the great necessity for retaining the surface soil. As a result of cropping and wind erosion, the organic matter in the cultivated soils was decreased 18.0% and the nitrogen 15.0%. Very little difference occurred in the nitrogen and organic matter content of the cropped and virgin subsurface soils.

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THE INTENSITY OF REMOVAL OF ADDED CATIONS FROM SOIL COLLOIDS BY ELECTRODIALYSIS[1]

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RECENT developments in physics and chemistry make available to biological workers a large amount of factual material concerning elements and compounds which are important in the study of soil colloidal complexes and plant nutrition. These developments make it possible to do more inductive research work instead of depending largely upon results secured by empirical methods. The theoretical and some of the more important phases of this general subject have been presented at length in previous papers (3, 4, 5, 6, 7).[3]

Data are presented which illustrate some of the results which might be predicted from the electrochemical properties of certain soil constituents used as plant nutrients. Every form of energy may be considered as compounded of two factors, one the intensity factor and the other the capacity factor. The data presented are largely concerned with the intensity factor and only incidentally with the capacity or quantity factor. The intensity factor is of primary importance in determining the intensity of removal of cations from soil colloidal complexes and in nutritional studies. The capacity factor and solubility of materials are important factors in soil formation processes. It has been noted that there is a close correlation between the intensity factor and the intensity of removal of certain atomic cations from soil colloidal complexes and the mineral constituents of certain plants.

METHODS EMPLOYED IN ELECTRODIALYSIS STUDIES

A soil designated as Hyde clay loam secured from eastern South Carolina was used in the fractional dialysis studies. The soil was passed through a 60-mesh sieve. The colloidal content, as determined by the Bouyoucos (1) hydrometer method, was 43.76%. The pH value of the original soil and after 24 hours of electrodialysis with a Bradfield three-compartment type electrodialysis cell was 4.64 and 3.55, respectively. The electrodialyzed soil had a cation exchange capacity of 17.5 M.E. per 100 grams of soil as determined by saturation with 1.0 N solution of ammonium acetate and distillation of the adsorbed ammonium.

Portions of the electrodialyzed soil were prepared for the electrodialysis studies by treating them separately with 1.0 N solutions of rubidium, potassium, sodium, lithium, calcium, and magnesium chlorides and the excess chlorides removed by washing with alcohol until tests with silver nitrate gave no precipitate. The two procedures used in determining the intensity of extraction of added cations are as follows: First, using a composite soil sample composed of four separate soil samples to which different metallic cations had been added; and second, using a soil sample containing only one added metallic cation. A 20-gram composite soil

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[3]Figures in parenthesis refer to "Literature Cited", p. 608.

sample, composed of equal amounts of the potassium, sodium, calcium, and magnesium treated soil samples, was used in the simultaneous extraction of cations by electrodialysis. Fifteen-gram samples were used in determining the intensity of extraction of cations from soil samples containing only one added cation. Fractions of the diffusates were collected at 2-hour intervals for the first 16 hours and at 8-hour intervals for the next 16 hours making a total of 32 hours of electrodialysis.

The usual methods were employed in making determinations of the amount of cations removed simultaneously from the composite soil sample (14). Calcium was precipitated as the oxalate and titrated with 0.05 N $KMnO_4$ solution. Magnesium was precipitated in the filtrate as magnesium ammonium arsenate and titrated with 0.1 N H_2SO_4. The final filtrate was acidified with a few drops of concentrated H_2SO_4 and the content evaporated to dryness. Potassium was determined as the chloroplatinate and sodium was estimated by difference. The methods employed in determining the intensity of extraction of cations from soil samples containing one added cation are as follows: Rubidium was precipitated with stannic chloride solution and weighed as rubidium chlorostannate (10); lithium was converted into the sulfate and weighed as such (15); calcium, magnesium, and potassium were determined as indicated above and sodium was precipitated with uranyl-zinc acetate and weighed as uranyl-zinc-sodium acetate (2).

RESULTS OF ELECTRODIALYSIS

The data secured in these studies are presented in Tables 1, 2, and 3 and in Figs. 1 and 2. The M.E. per 100 grams of soil and the percentage of the total for each element for every period are included.

TABLE 1.—*Intensity of removal of two added cations by fractional electrodialysis from a composite soil sample.*

Period of extraction in hours	Milliequivalents per 100 grams air-dry soil			
	K		Ca	
	M.E.	%	M.E.	%
0–2	5.41	55.3	0.79	8.8
2–4	1.10	11.2	1.50	16.6
4–6	1.20	12.3	1.30	14.4
6–8	0.47	4.8	0.86	9.5
8–10	0.27	2.8	0.63	7.0
10–12	0.28	2.9	0.58	6.4
12–14	0.17	1.7	0.58	6.4
14–16	0.17	1.7	0.50	5.5
16–24	0.41	4.2	1.47	16.3
24–32	0.30	3.1	0.83	9.1
Total	9.78	100.0	9.04	100.0

The percentage removal of the various metals for each extraction period shows that there is a differential in the intensity of removal of the cations when they are extracted simultaneously. The percentage of the total amounts of potassium and calcium extracted, shown in Table 1, during the first 2-hour period was 55.3 and 8.8, respectively, whereas the percentage extracted during the 14-hour

TABLE 2.—*Intensity of removal of four added cations by fractional electrodialysis from a composite soil sample.*

Period of extraction in hours	Milliequivalents per 100 grams air-dry soil							
	K		Na		Ca		Mg	
	M.E.	%	M.E.	%	M.E.	%	M.E.	%
0–2	1.54	56.00	0.90	24.66	0.74	17.49	0.49	11.98
2–4	0.26	9.44	0.41	11.23	0.99	23.40	0.49	11.98
4–6	0.16	5.82	0.40	10.96	0.69	16.31	0.64	15.65
6–8	0.12	4.37	0.33	9.04	0.29	6.86	0.49	11.98
8–10	0.13	4.73	0.24	6.58	0.29	6.86	0.45	11.00
10–12	0.11	4.00	0.35	9.59	0.29	6.86	0.42	10.27
12–14	0.11	4.00	0.28	7.67	0.29	6.86	0.24	5.87
14–16	0.08	2.91	0.24	6.58	0.24	5.67	0.28	6.84
16–24	0.10	3.64	0.38	10.41	0.22	5.20	0.24	5.87
24–32	0.14	5.09	0.12	3.28	0.19	4.49	0.35	8.56
Total extracted	2.75	100.00	3.65	100.00	4.23	100.00	4.09	100 .0
Total added	4.77		4.82		4.22		4.37	
Percentage extracted	57.65		75.73		100.00		93.59	

to 16-hour period was 1.7 and 5.5, respectively. Table 2 and Fig. 1 present the intensity of removal of four cations extracted simultaneously from a composite soil sample. The percentage of the total amounts of potassium, sodium, calcium, and magnesium extracted during the first 2-hour period was 56.00, 24.66, 17.49, and 11.98, respectively. These data suggest that much of the exchangeable potassium is very readily removed from certain soil colloids. Furthermore, it is of interest to note that the intensity of removal of sodium in the first extraction period from this particular colloidal material is less than the intensity of removal of potassium, and that the intensity of removal of calcium is less than sodium and magnesium is less than calcium. The total M.E. of potassium and sodium extracted for the first 12 hours of electrodialysis are 2.32 and 2.63, respectively. If long dialysis periods are considered, one may conclude that sodium is more readily removed than potassium.

The order of intensity of removal of cations from soil samples containing only one added cation is shown in Table 3 and Fig. 2. The original soil was electrodialyzed for 24 hours and portions treated separately with molecular equivalent quantities of the chlorides of rubidium, potassium, sodium, lithium, calcium, and magnesium. The percentages of the various materials removed in the first extraction period illustrate very clearly the differential in intensity of the removal of cations from soil colloids. The order of intensity of removal of rubidium is highest, with potassium, sodium, lithium, calcium, and magnesium following in the order named.

The results secured in these studies are in agreement with those obtained by Koenig, *et al.* (11) and by Wilson (16) on the intensity of removal of potassium, calcium, and magnesium ions from soils by electrodialysis.

Both the simultaneous and separate extractions show that cations

TABLE 3.—*Intensity of removal of cations by fractional electrodialysis from soil samples containing only one added cation.*

Period of extraction in hours	Milliequivalents per 100 grams air-dry soil											
	Rb		K		Na		Li		Ca		Mg	
	M. E.	%	M. E.	%	M. E.	%	M. E.	%	M. E.	%	M. E.	%
0–2	4.84	91.32	4.49	60.51	3.19	53.43	3.65	43.15	5.64	36.89	2.38	24.31
2–4	0.19	3.58	0.95	12.80	0.91	15.24	1.05	12.41	3.12	20.40	2.01	20.53
4–6	0.10	1.89	0.38	5.12	0.80	13.40	0.62	7.33	1.66	10.86	0.90	9.19
6–8	0.04	0.75	0.32	4.31	0.11	1.84	0.64	7.57	1.88	12.30	0.61	6.23
8–10	0.02	0.38	0.23	3.10	0.13	2.18	0.42	4.96	0.98	6.40	0.65	6.64
10–12	0.02	0.38	0.25	3.37	0.12	2.01	0.32	3.78	0.58	3.79	0.58	5.93
12–14	0.00	0.00	0.15	2.02	0.17	2.85	0.38	4.49	0.41	2.68	0.61	6.23
14–16	0.02	0.38	0.18	2.43	0.20	3.35	0.40	4.73	0.45	2.94	0.58	5.93
16–24	0.00	0.00	0.23	3.10	0.12	2.01	0.56	6.62	0.39	2.55	0.68	6.94
24–32	0.07	1.32	0.24	3.24	0.22	3.69	0.42	4.96	0.18	1.18	0.79	8.07
Total extracted	5.30	100.00	7.42	100.00	5.97	100.00	8.46	100.00	15.29	100.00	9.79	100.00

are removed differentially from soil colloids by electrodialysis and that the intensity of removal of cations is correlated with what has been called the chemical potential or chemical intensity, which is the driving force of a reaction, of certain common soil metals. The electromotive series appears to be one of the best groupings of elements according to the intensity factor of electrical or chemical energy. Since the standard electrode potentials are a relative measure of the intensity factor of energy, they should be of special interest in cationic exchange and nutritional studies (3, 5, 6, 7).

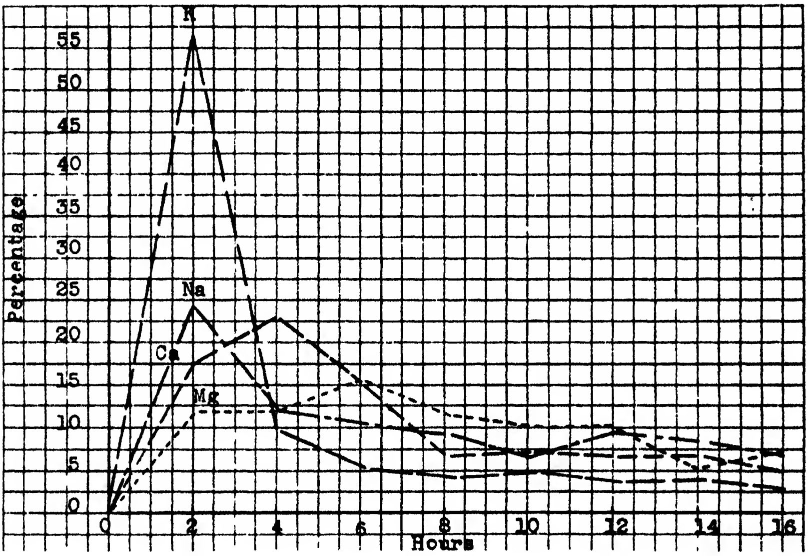

FIG. 1.—Percentage of the total M. E. of added cations removed from a composite soil sample during the 2-hour periods for the first 16 of the 32 hours of electrodialysis.

It should not be overlooked that this series represents the potential difference in volts which is developed between metals and solutions of their salts. The limitation of this series should be taken into consideration in interpreting the activity of ions in a complex system such as soils. The intensity of removal observed for the various materials studied is that which would be expected from their known electrochemical properties.

RELATION OF IONIZATION POTENTIALS TO INTENSITY OF REMOVAL OF METALLIC CATIONS FROM COLLOIDS

It is highly probable that the intensity of removal of atomic cations from soil colloidal complexes is also closely correlated with the compiled ionization potentials of metals given in Table 4 (5, 12, 13). The approximate energy of removal, in equivalent volts, of the inmost normal valence electrons of elements to form atomic ions ranges from Rb^+ 4.15 volts to Al^{+++} 28.30 volts, as shown in Table 4.

TABLE 4.—*Energy relationships and ionization potentials and the order of ions in various stages of ionization.**

Approximate equivalent energy for the removal of valence electrons			
Removal of last bound electron		Removal of inmost normal, or common, valence electron	
Element	Equivalent volts	Element	Equivalent volts
Rb^+	4.15	Rb^+	4.15
K^+	4.33	K^+	4.33
Na^+	5.15	Na^+	5.15
Li^+	5.42	Li^+	5.42
Al^+	5.96	Ca^{++}	11.78
Ca^+	6.09	H^+	13.54
Mn^+	7.45	Mg^{++}	15.03
Mg^+	7.58	Mn^{++}	15.73
Fe^+	7.85	Fe^{++}	16.52
H^+	13.54	Al^{+++}	28.30

*Energy corresponds to the passage from the most stable state of the atom to the most stable state of the ion.

These values represent the relative intensity with which the different valence electrons are bound in the various metals. These basic values may be very useful in soil and nutritional problems. The use of such material necessitates an understanding of the fundamental principles involved, otherwise these values will be of little use in interpreting results obtained in soil and nutritional studies. It is probable also that the intensity of removal of atomic cations from the exchange complexes of soils by electrodialysis is more closely correlated with this grouping than with the electromotive series or displacement grouping of elements (3, 5, 6, 7). Additional ionization potentials are included in a previous paper (5). The ionization potential values given in Table 4 suggest an interpretation for the relatively large amounts of hydrogen ions in certain soil colloidal complexes. The metals which fall below calcium in the electromotive series are not capable of dominating the hydrogen ions, therefore soils usually become acid in reaction when the quantity of calcium or the metals above calcium in the electromotive series become low in the colloidal complex.

Hydrogen is found between calcium and magnesium in this grouping. The single valence electron of hydrogen is not as strongly bound as the inmost normal valence electron of magnesium, therefore only relatively small quantities of exchangeable magnesium would be expected to be present in the colloidal complex of most non-saline soils. Since the energy of removal of next to the last bound electron from manganese and iron to form Mn^{++} and Fe^{++} is 15.73 and 16.52 equivalent volts, respectively, only small quantities of these metals would be expected to be present in the exchange complex of soils. An element such as aluminum with an energy of removal of the inmost normal valence electron of 28.30 equivalent volts would not be expected to be removed in atomic form, but it would be expected to form complex ions in most non-saline soils. The energy of removal of valence electrons from aluminum to form Al^+, Al^{++}, and Al^{+++} is 5.96, 18.17, and 28.30 equivalent volts, respectively.

The adsorption and removal of an electrolyte from a soil appears as an additive property of its ions. The quantitative adsorption and removal of any individual added cation is influenced by the solubility of the compound it may form in the soil complex. Since the solubility of soil metals differs markedly depending upon the anions present, the relative amounts of the various anions present is a very important factor in determining the removal of any particular cation from the soil and its availability to plants.

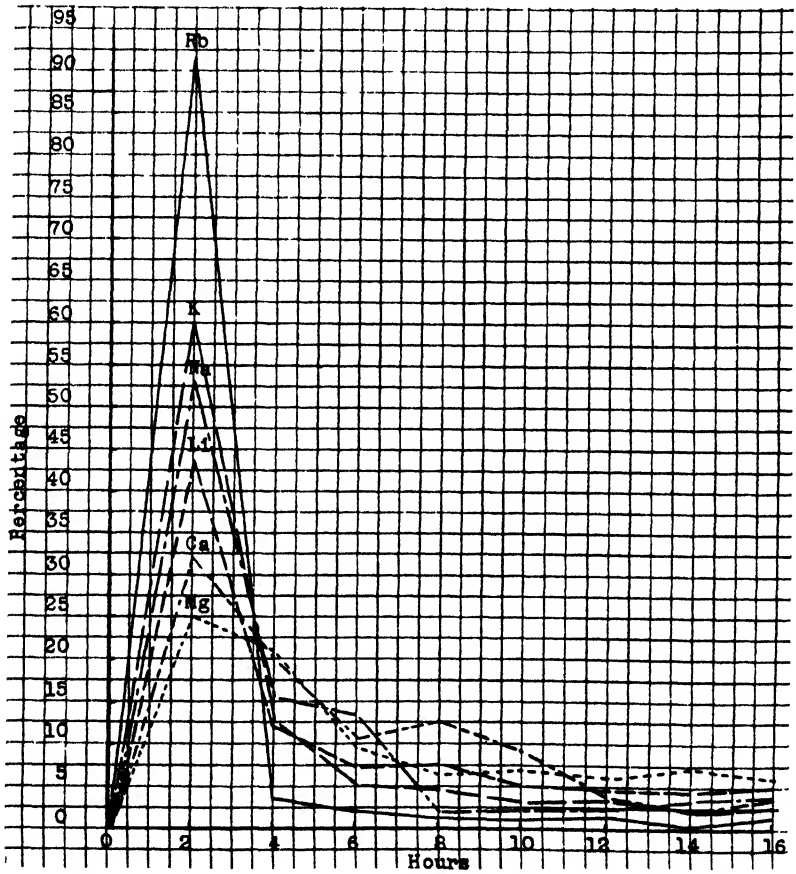

FIG. 2.—Percentage of the total M. E. of cations removed from soil samples containing only one added cation during the 2-hour periods for the first 16 of the 32 hours of electrodialysis.

RELATION OF SOLUBILITY VALUES TO AVAILABILITY AND LOSS OF NUTRIENTS FROM SOILS

The significance of solubility values in accounting for the loss from the soil and the availability of plant nutrients is shown in Table

5. This table shows the relation between magnesium deficiency symptoms in the cotton plant and the source of nitrogen in the fertilizer. The data were secured from a source-of-nitrogen fertilizer experiment where 50 pounds of nitrogen were applied per acre on Norfolk loamy sand. The percentage of red leaves due to a deficiency of available magnesium was determined on August 11. The magnesium deficiency was much more pronounced on the sodium nitrate and ammonium sulfate plats than on ammoniated superphosphate and Ammo-phos plats. There was only a trace of magnesium deficiency on the plats which received both ammonium sulfate and basic slag. The magnesium in the basic slag supplied sufficient magnesium for the cotton plant.

TABLE 5.—*The relation between magnesium deficiency symptoms in cotton plants and the source of nitrogen fertilizer, Sandhill S. C. Experiment Station, 1932.*

Source of nitrogen	Percentage of red leaves on plants on Aug. 11
Sodium nitrate	28.3
Cal-Nitro	24.5
Ammonium sulfate	24.2
Calcium Cyanamid	24.2
Urea	20.3
Ammoniated superphosphate	18.4
Ammo-phos	2.7
Ammonium sulfate+basic slag	1.0

The relation between the magnesium deficiency and the source of nitrogen is very probably due to the differences in the solubility of the magnesium salts formed by the addition of the various nitrogen carriers. The molar solubilities of certain magnesium salts are as follows: Magnesium nitrate 5.00, magnesium sulfate 2.88, and magnesium phosphate 0.002. Where nitrates are added to the soil some magnesium nitrate is formed by their reaction with the magnesium in the soil. Since magnesium nitrate is very soluble, a relatively large amount of magnesium nitrate may be lost in the drainage water. Likewise, when soluble sulfates are added to the soil, there may be a considerable loss of magnesium in the drainage water as magnesium sulfate; but where ammonium phosphate was added, as in this experiment, there was only 2.7% of the leaves colored red. The formation of magnesium ammonium phosphate, which is only slightly water soluble, very probably tends to prevent the leaching of magnesium from the soil. The differences in the magnesium deficiency symptoms of the plants were more marked early in the season than later when these counts were made (August 11). Since the order of magnesium deficiency is in direct ratio to the order of solubility of the above salts, support is given to the above interpretation of the magnesium deficiency observed where the various sources of nitrogen are used.

Since solubility of compounds is such an important factor in determining the adsorption and the removal of various materials

from soil complexes and their availability to plants, this topic should be given careful consideration in soil fertility investigations. Ions which form relatively insoluble complexes in the soil, such as the potassium and hydrogen ions, may be strongly fixed and are difficult to remove completely from certain soil complexes, whereas such ions as sodium and calcium are not as difficult to remove from certain colloidal complexes. Table 6 gives the compiled approximate molar solubility of materials which may be present in certain soil complexes (5, 8). It is noted that there is a wide difference in the solubility of the hydroxides of the metals commonly present in soils. The total quantity of metallic materials removed from soil colloidal complexes by electrodialysis may be correlated with the solubility of their hydroxides. The solubility of the hydroxides of the following metals listed in the decreasing order of solubility are as follows: Sodium, potassium, calcium, magnesium, iron, manganese, and aluminum. These solubility values of the hydroxides show why manganese is sometimes the first minor nutrient to become deficient on certain Coastal Plain soils that have been heavily limed.

Only small quantities of such materials as manganese and iron are removed by electrodialysis, whereas relatively large quantities of these elements may be removed by leaching soils with acetates or chlorides (16). The approximate molar solubilities of manganese and iron chlorides are 5.93 and 5.68 moles, respectively. For this reason it should not be overlooked that there is a wide variation in the solubility of the materials formed in soils by the various solutions commonly used in extracting cations from soil colloids. This makes it difficult to correlate the data secured by electrodialysis and by leaching soils with solutions of various electrolytes.

Since this paper is primarily concerned with the intensity of removal of ions and not the capacity or total amount removed, no attempt has been made to correlate this work with data secured by leaching soils with salt solutions. It is believed that the intensity factor of removal of ions correlates more closely with the intensity of adsorption of nutrient ions by plants than the capacity factor or quantity removed. Jenny (9) has made very valuable contributions on the quantitative order of removal of various cations from soil colloidal complexes by salt extractions.

It may also be observed from a study of Table 6 that salts formed from isosteric ions are usually less soluble than similar salts formed from non-isosteric ions. The relationship between the position of the elements in the periodic chart of the atoms and the solubility of certain simple compounds has been discussed in a previous paper (5). The solubility of the salts of the alkali metals and the halogens appears to be in direct proportion to the magnitude of the difference between the atomic numbers with the exception of lithium iodide. For example, the molar solubility of the chlorides of lithium, sodium, and potassium included in Table 6 is 18.80, 6.13, and 4.61 moles, respectively. Potassium, which forms argon-like cations, very probably forms relatively insoluble complex compounds by combining with anionic materials in the soils which may form argon-like anions such as silicon. Sodium, which forms neon-like cations, would not be so

TABLE 6.—*Molar solubility of various materials; most determinations made around 20° to 30° C.*

Ion	Rb	K	Na	Li	Ca	Mg	Al	Mn	Fe	Cu
F	—	16.60	1.00	0.10	0.0002	0.0014	Sol.	Insol.	—	—
Cl	7.53	4.61	6.13	18.80	6.70	5.76	2.61	5.93	5.68	5.58
Br	6.68	5.42	8.77	20.00	7.10	5.25	Sol.	6.60	5.20	—
I	7.16	8.63	11.98	12.00	7.00	5.03	—	—	—	—
SO_4	1.79	0.64	1.33	3.12	0.015	2.88	1.06	4.49	1.74	1.30
NO_3	3.65	3.08	10.31	10.50	7.88	5.00	3.01	7.66	4.67	6.56
CH_3COO	40.70	25.98	5.60	5.77	2.20	Deliques.	Sol.	0.122	—	0.39
C_2O_4	—	2.09	0.24	0.61	0.00004	0.0027	—	0.0016	0.00012	0.00016
CO_3	9.60	8.00	2.09	0.18	0.00013	0.01	—	0.001	Insol	Insol.
OH	17.50	19.90	27.20	5.32	0.022	0.0002	Insol.	0.000005	0.00007	Insol.

apt to form many complex relatively insoluble compounds in the soil since there would be a relatively small amount of materials in soil colloidal complexes which would form neon-like anions. Most of the important metallic cations in the soil colloidal complex in humid climates tend to form argon-like ions. There would be less tendency, therefore, to form many insoluble compounds with such materials as sodium which forms neon-like ions and lithium which forms helium-like ions. Large quantities of lithium and sodium would not be expected in the colloidal complex of soils in humid climates since there would be little chance for these materials to be held in soil due to the solubility of compounds formed. Potassium and chlorine ions are both argon-like; therefore, potassium chloride which is composed of isosteric ions would be expected to be less soluble than sodium chloride or lithium chloride which are composed of non-isosteric ions. The sodium ion is neon-like and the chlorine ion is argon-like, consequently they are not isosteric. The lithium ion is helium-like and lithium chloride would be expected to be more soluble than sodium chloride.

On certain soils which have received heavy applications of fertilizer, or certain other soil amendments, the so-called minor plant nutrients often become the limiting factor in crop production. Since a relatively large proportion of the commercial fertilizer is used on soils where there may be a marked response in plant growth from either a deficiency or excess of some of these minor nutrients, such as magnesium, manganese, and copper, a study of the solubility values included in Table 6 should aid materially in an interpretation of some of the results obtained on some of the soils. The significance of these solubility values will be given further consideration in another article concerning the availability of the minor plant nutrients.

SUMMARY

Information is presented which supports the suggestion that there is a close relationship between the oxidation-reduction potentials of nutrient materials and the intensity of their removal from soil complexes by electrodialysis.

Samples of soil were electrodialyzed for 24 hours and definite amounts of soil were treated with a single salt solution. A composite sample made from the soil samples treated with potassium and calcium chlorides was electrodialyzed for 32 hours. Samples of the diffusate were collected at 2-hour intervals for the first 16 hours and at 8-hour intervals for the second 16 hours. Soil samples containing a single added cation were electrodialyzed in a similar manner.

The data presented illustrate very clearly the differential in intensity of removal of the various metals from soils by electrodialysis. There is a correlation between the intensity of removal of certain cations from soils and the strength of ions. The strongest ions are removed most rapidly from the soil. A large proportion of the strong cations was found in the first two fractions of the diffusate.

Oxidation-reduction potential values and ionization-potential values are useful in predicting the intensity of removal of cations from soils by electrodialysis.

The adsorption and removal of an electrolyte from a soil appears as an additive property of its ions. It appears that the quantitative adsorption and removal of any individual added cation is probably influenced by the solubility of the compound or compounds it may form in the soil complex. Added sodium and calcium which apparently form relatively soluble complexes in the soil may be removed more completely than added potassium which apparently forms certain relatively insoluble compounds in the soil.

The solubility values of various electrolytes may be of great value in an interpretation of some of the striking growth responses of crops observed from inadequate or excessive amounts of the so-called minor plant nutrients. In areas using heavy applications of commercial fertilizer the insufficient quantities of the minor plant nutrients in the soil are often the limiting factors in determining crop yields.

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SOIL LIMING INVESTIGATIONS: I. THE CALCIUM CARBONATE EQUILIBRATION METHOD OF LIMING SOILS FOR FERTILITY INVESTIGATIONS[1]

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WHEN liming materials are applied to soils in large amounts, marked changes are induced in the physical, chemical, and biological properties of soils. The influence of lime on many of these properties has been reported in the literature, but there is some disagreement in the results. Furthermore, there are considerable apparently conflicting results on the effect of lime on soil productivity or plant growth (6, 11, 12)[3]. There is not complete agreement on the lime requirement of soils either from the standpoint of laboratory or field methods. The methods for the former have been more or less empirical (4, 5, 10), while for the latter the general procedure has been by trial and error. Thus, there is a real need for a more suitable liming method in order to investigate the effects and feasibility of liming soils as well as to study the lack of agreement in previous investigations.

A liming method by which increments of lime are added to the soil instead of a single amount as previously proposed(4, 5, 10) would be advantageous in that a yield curve could be obtained. A soil constant or an equilibrium point would be necessary for such a liming method in order that comparable results could be obtained on widely different soils. The saturation point of soils defined by Bradfield and Allison (2) seems admirably suited for a base point for the liming method. A saturated soil is defined by them as one at equilibrium with an excess of solid $CaCO_3$ and the CO_2 partial pressure of the atmosphere at 25° C. In many respects this point is perhaps the nearest approach to a soil constant yet studied. The addition of increments of lime to the point of saturation and beyond this point will result in the complete range of pH values and degrees of base saturation from that of the unlimed soil to completely saturated soils. Both soil reaction and base saturation are generally considered to influence soil fertility. The proposed liming method includes not only the maximum amount of lime which will react with the soil, but also increments below and above this amount if desired.

It appears that the method proposed would be applicable to the study of widely different soils, especially since *liming injury* may or may not occur on all soils. Liming soils in greenhouse cultures or on field plats by this method should give results from which the optimum amount of lime for certain crops or cropping systems could be obtained. A search of the literature revealed no systematic study of

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[3]Reference by number is to "Literature Cited", p. 621.

greenhouse or field soils as proposed in this method which may be termed the $CaCO_3$ equilibration method.

The purpose of this paper is to report results on the applicability of the $CaCO_3$ equilibration method of liming to soil fertility investigations. The specific studies included are (a) the "Ca-sorption capacities" of soils and a comparison with the Pierre (10) liming method, (b) the lime requirements of soils and crops in the greenhouse, (c) the sorption of Ca by electrodialyzed soil colloids, (d) the influence of lime on the sorption of K, and (e) the influence of lime on the nitrification of $(NH_4)_2SO_4$.

LABORATORY PROCEDURE

The standard procedure used for equilibrating the soil suspensions was a serial titration. Twenty grams of air-dry 40-mesh soil were added to each of a series of 12 250-cc Squibb separatory funnels. Increasing amounts of standard 0.03 N $Ca(OH)_2$ were added to the soils leaving one untreated, and water was added to make the soil-water ratio 1 to 2.5, except in the case of colloidal clays where a 2% suspension was used. Carbon dioxide was bubbled through the suspensions for 15 to 20 minutes, and this was followed with 18 to 24 hours aeration with air. The suspensions were immediately used for specific conductivity measurements and then the pH values were obtained with the glass electrode (7). These two sets of values were plotted and smooth curves were drawn on coordinate paper. From this the amount of Ca sorbed by the soil, "Ca-sorption value", was obtained. The native exchangeable Ca determined by the NH_4Ac method was added to the Ca-sorption value and the sum taken as the Ca-sorption capacity of the soil. An illustration of these values is given in Fig. 1.

This procedure gave 1.4 M.E. of total base, Ca^{++}, per liter of solution at 25° C when either a solution of .03N $Ca(OH)_2$ or a saturated solution of $CaCO_3$ was equilibrated. The pH values of the two equilibrated Ca solutions were 8.2 and 8.0, respectively; the latter value was low which was probably due to super saturation. Considerable preliminary work was necessary to develop the technic for bringing the soils to equilibrium with the atmospheric CO_2 and the added Ca. It was found that if the equilibrated soil suspensions were allowed to stand in closed flasks for several days, the equilibrium was disturbed by the accumulation of CO_2 from bacterial action and the pH values were lowered considerably. The process is completely reversible, however, and the suspension may be restored to its former state of equilibrium by proper aeration (Fig. 2). There is apparent need for careful study of previous data obtained in calcium saturation studies by other investigators where $Ca(OH)_2$ was added to the soil or colloidal suspensions in sorption studies.

RESULTS

THE CA-SORPTION CAPACITY OF SOILS

Sorption curves for several important soil types are shown in Fig. 3, and the Ca-sorption values are included in Table 1. There was a wide range in the amount of Ca sorbed by the different soils. The sum of this value and the native exchangeable Ca gives the Ca-sorption capacity which obviously was widely different for the various soils. The amount of native exchangeable Ca does not affect the sorption capacity but does reflect itself in the Ca-sorption value. This is illustrated in the results of the Lufkin clay where the latter

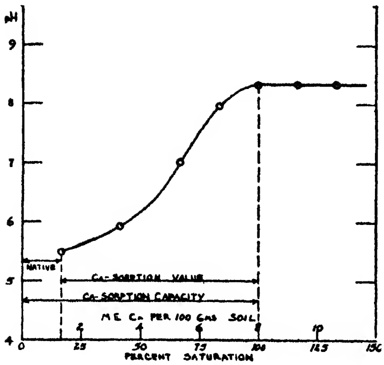

Fig. 1.—The calcium carbonate equilibration method of liming soils.

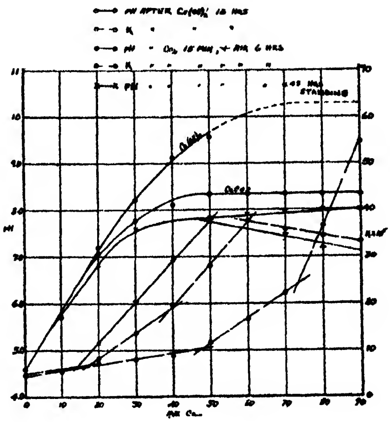

Fig. 2.—Air-$CaCO_3$-H-Clay equilibria, Decatur E. D. colloid.

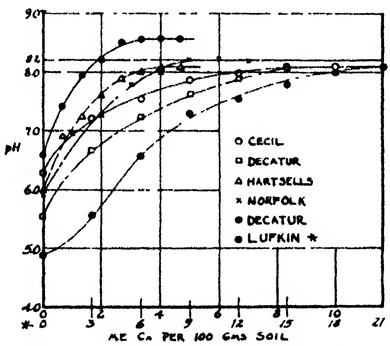

Fig. 3.—Ca-sorption curves of soils.

value was 18.00 M. E. and the exchangeable Ca was 15.12 which gave 33.12 M. E. as the Ca-sorption capacity. According to Bradfield and Allison (2), the presence of exchangeable Mg does not influence the sorption of Ca at the equilibrium point. If this is true, the variation in the values for the NH_4Ac exchange capacity and the Ca-sorption capacity must be due mainly to the increased sorption at the higher reaction.

Table 1.—*Soil type and chemical composition of several important soil series.**

Soils		pH	$\frac{SiO_2}{R_2O_3}$ colloid	Exchangeable bases with NH_4Ac			$CaCO_3$ equilibration method	
No.	Soil type			Total	Ca	Mg	Ca-sorption value	Ca-sorption capacity
934	Cecil, C	6.32	1.60	10.00	4.54	0.94	8.33	12.87
935	Decatur. CL	5.75	1.75	8.75	3.39	1.24	8.00	11.39
936	Hartsells, SL	6.10	1.70	3.20	1.65	0.39	4.00	5.65
937	Norfolk, FSL	6.10	1.10†	3.25	1.26	0.54	5.00	6.26
938	Delta, VFSL	6.60	2.70	10.20	7.18	2.11	3.33	10.51
939	Lufkin, C	4.75	3.82	34.15	15.12	8.39	18.00	33.12

*Values in M.E. per 100 grams of soil.
†From Davis (3).

The reaction of all the soils at the equilibrium point was approximately the same except that of the Delta soil (Fig. 3). The latter value might have been high due to the hydrolysis of strong bases replaced by the Ca. The reaction of the Ca-saturated suspensions shows the extent to which the pH values can be changed through the use of lime. The pH curves are typical buffer curves which tend to characterize the nature of the colloidal fraction of the soils (1). That is, the curve for the Lufkin clay shows a much higher buffer capacity than the other soils, and this is reflected by the $SiO_2 = R_2O_3$ ratio of the soils. The amounts of lime to be added to the greenhouse soils were taken from these curves; therefore, the pH values of the greenhouse soils should tend to follow the course of the laboratory curves.

COMPARISON OF CA-SORPTION DATA WITH OTHER DATA ON FOUR SOIL SERIES

Soil samples, their chemical analysis, and their lime requirement as determined by Pierre's method were furnished by Davis (3) for comparison with the $CaCO_3$ equilibration method. Data of this study are given in Table 2 for five soils and one subsoil for each of Norfolk, Greenville, Decatur, and Hartsells series. Of the 24 samples, 16 gave Ca-sorption capacities greater than the NH_4Ac exchange capacities, 3 were equal, and the remaining 5 samples were less. Obviously, the Ca-sorption value, the amount of lime necessary to bring the soil to pH 8.20, should be greater than the Pierre lime requirement which limes to pH 6.5 including a liming factor. This was true except for four soils, a condition which was probably due to limitations of the latter method.

Soil No. 916 was 106% saturated with Ca as determined by NH_4Ac, obviously an error of that method. With the $CaCO_3$ equilibration method it was only 64.2% saturated. There was a fair correlation between the Ca-sorption capacity and the colloidal content of the soils for a given series. This is likely influenced by the $SiO_2 = R_2O_3$ ratio of the soil.

LIME REQUIREMENTS OF SOILS AND CROPS AS DETERMINED IN THE GREENHOUSE

The six soils (Table 1) were limed in increments of 25% of the Ca-sorption value over the range 0 to 100%. The amounts of lime required for this treatment were taken from the sorption curves (Fig. 3). The soils were limed in two series, one with $CaCO_3$ and the other with $Ca.Mg(CO_3)_2$ in triplicate pots of 8 kilos of air-dry soil. Two crops of sorghum and a crop of soybeans were grown on the soils with the addition of a constant amount of N, P, and K fertilizers to each crop. It was proposed to obtain the optimum amount of lime, *lime requirement*, for the different crops on these soils, and also to study liming injury if such occurred on the soils.

Crop yields and soil reaction after the first crop are given in Table 3, which also shows the arrangement of the experiment. It is quite evident that this crop was little affected by the lime applications. There was a slight decrease in yields on the Decatur and Hartsells

TABLE 2.—*Soil analyses and Ca-sorption data on four soil series.*

Soil series	Lab. No.	Data from Davis (3)							Ca-sorption data		
		pH	% colloid	SiO_2 / R_2O_3	Exchange capacity	Exchange Ca	% Ca saturation	Lime requirement	Ca-sorption value	Ca-sorption capacity	% Ca saturation
Norfolk.....	775	4.78	11.1	1.16	7.48	0.86	11.5	10.2	7.90	8.76	9.8
Norfolk.....	776	5.00	8.7	1.30	5.74	0.58	10.1	7.9	5.21	5.79	10.0
Norfolk.....	781	5.88	3.8	1.65	3.23	0.93	28.8	2.3	2.36	3.29	28.3
Norfolk.....	783	5.90	8.0	1.59	4.89	1.76	36.0	1.9	5.05	6.81	25.8
Norfolk.....	791-A	5.48	8.3	1.26	4.37	0.68	15.5	4.6	5.05	5.73	11.8
Norfolk.....	791-B	4.93	22.7	1.24	6.93	0.69	9.95	4.6	5.67	6.36	12.3
Greenville ..	801	5.20	14.3	1.17	9.71	1.89	19.4	3.36	6.50	8.39	22.5
Greenville ..	802	5.20	8.8	1.21	3.17	0.65	20.4	1.14	2.25	2.90	22.4
Marion.....	813-A	6.10	7.9	1.33	3.44	2.44	71.0	0.40	2.10	4.54	53.0
Marion	813-B	6.40	26.0	1.43	5.94	3.27	55.0	0.10	1.60	4.87	67.0
Greenville ..	817	6.40	10.6	1.74	2.98	2.68	90.0	0.30	1.90	4.58	58.6
Marion.....	821	6.00	7.9	1.74	2.85	2.28	85.2	0.33	1.40	3.68	62.0
Decatur....	886	5.30	37.96	1.56	8.80	2.91	33.0	1.98	6.32	9.23	31.6
Decatur....	890	5.40	30.04	1.68	11.42	5.01	43.8	1.72	6.32	11.33	44.4
Decatur....	893	6.30	26.02	1.88	9.31	6.85	73.5	0.22	4.42	11.27	61.7
Decatur....	894	5.90	30.01	1.87	9.88	5.70	57.8	0.62	5.69	11.39	51.2
Decatur....	903-A	4.95	30.52	1.81	8.75	3.07	35.0	2.48	8.85	11.92	25.8
Decatur....	903-B	5.00	39.12	1.76	13.13	2.88	21.9	2.62	8.43	11.31	25.5
Hartsells....	916	7.35	3.85	1.64	4.91	5.21	106.0	0.0	2.80	8.01	64.2
Hartsells....	918	5.40	5.40	1.66	3.02	1.25	41.4	3.52	3.75	4.00	31.3
Hartsells ..	927	6.00	4.93	1.71	3.44	1.74	50.6	2.28	4.35	6.09	28.6
Hartsells....	931-A	5.55	5.49	1.76	4.26	0.84	19.7	6.00	6.51	7.35	11.4
Hartsells....	931-B	4.95	14.71	1.79	4.91	0.96	19.5	8.40	6.30	7.26	13.2
Hartsells	933	5.40	3.54	1.76	6.06	1.20	19.8	7.14	6.25	7.45	16.1

TABLE 3.—*Reaction of soil and yield of first crop of sorghum.**

Ca-sorption value %	pH values and yields on different soils											
	1 Cecil		2 Decatur		3 Hartsells		4 Norfolk		5 Delta		6 Lufkin	
	pH	Weight	pH	Weight	pH	Weight	pH	Weight	pH	Weight	pH	Weight
					Calcium							
0†	6.75	17.1	5.78	25.9	6.12	22.6	6.42	28.9‡	7.08	36.0‡	4.75	42.5‡
0	6.32	30.8	5.75	29.6	6.10	25.0‡	6.10	32.2	7.00	34.9†	4.75	44.8
25	7.09	27.2	6.55	30.4	7.00	24.5	6.69	33.0	7.70	32.2‡	5.72	43.3‡
50	7.68	27.9	7.24	25.5	7.65	24.5‡	7.50	33.4	8.00	31.9	7.35	43.2‡
75	8.05	29.5	7.72	25.2	8.22	24.1‡	8.07	33.1	8.12	31.1	7.80	45.1‡
100	8.10	30.3	7.90	23.4	8.20	20.1	8.40	32.9‡	8.05	31.6‡	7.95	46.5‡
					$\frac{\text{Calcium}}{\text{Magnesium}} = 1$							
25	7.00	27.5	6.67	29.7	7.00	25.8	7.15	34.8	7.45	33.7	5.80	43.7
50	7.62	27.1	7.32	28.4	7.68	25.5	7.40	33.7	8.00	34.2	7.05	45.3
75	8.00	26.7‡	7.80	27.2	7.88	24.0	8.00	32.5	8.26	31.1	7.70	43.8‡
100	8.10	28.7	8.02	23.5	8.03	29.6	7.97	32.3	8.25	28.5	7.96	43.5‡

*Average of replicates; weights in grams. Planted August 1, 1932, and harvested October 12, 1932.
†These cultures received P from KH_2PO_4 and others from superphosphate.
‡Replicates do not agree.

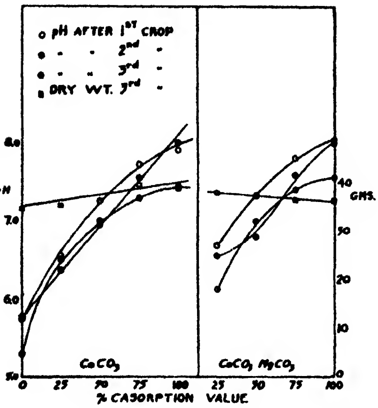

FIG. 4.—Greenhouse studies: Reaction of soil and yield of soybeans. II. Decatur clay loam.

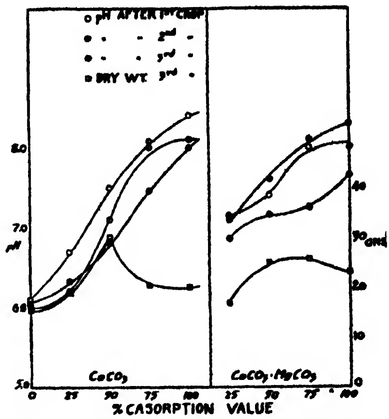

FIG. 5.—Greenhouse studies: Reaction of soil and yield of soybeans. IV. Norfolk sandy loam.

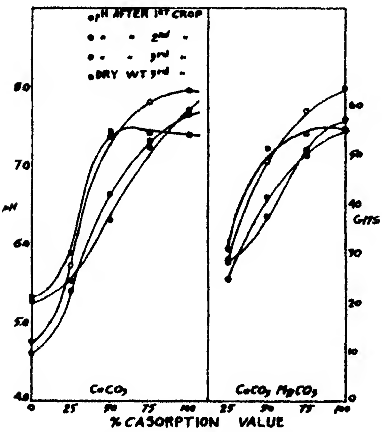

FIG. 6.—Greenhouse studies: Reaction of soil and yield of soybeans. VI. Lufkin clay.

soils at high degrees of Ca saturation, but in general the yield curves were practically horizontal lines. It is worty of note here that greenhouse yields of the first crop on soils freshly removed from soil profiles are often abnormally high. This is probably due to better aeration, structure, or other physical properties. The soil reaction was changed through the maximum range possible through the use of the lime, the maximum of all the soils being approximately pH 8.0.

The response of the soybeans, the third crop, to the lime treatments is shown in typical examples in Figs. 4, 5, and 6. The yields on the Decatur clay loam (Fig. 4) were not appreciably affected by either the calcic or dolomitic lime. This would indicate that over liming is not likely to occur on this soil. Yield curves on the Norfolk sandy loam (Fig. 5) pass through a maximum at increments of 50% of the Ca-sorption value in the case of calcic and 75% with dolomitic lime. These results indicate that liming injury is likely to occur on this soil. An enormous increase in yield was obtained on the acid Lufkin clay (Fig. 6) with maximum yields at increments of approximately 50% and 75% in the case of calcic and dolomitic lime, respectively. These results indicate little possibility of over liming in this soil. It should be noted that in this experiment the soils were limed to the

saturation point but not in excess of this; in later studies an excess of lime was added to study its effect.

It is interesting to note the changes in the pH curves in Figs. 4, 5, and 6, determined at the removal of the three crops at 3½, 8, and 11 months after liming the soils. The values show considerable increase in acidity with time. Many factors enter into this effect some of which are formation of soluble Ca compounds, accumulation of acid residues from acid fertilizers, and displacement of equilibrium conditions of the exchange complex.

RATE OF DECOMPOSITION OF ADDED $CaCO_3$ AND $Ca.Mg(CO_3)$

The residual carbonates by the Schollenberger (13) method were determined in duplicate composite samples from the greenhouse soils. The amounts of carbonates decomposed after 3½, 8, and 11 months in contact with the soil are given in Table 4 in terms of percentages of the total amounts of carbonates applied. There was a tendency toward higher percentages of decomposition in the most acid soils The $Ca.Mg(CO_3)_2$ lime decomposed more rapidly than $CaCO_3$ due to the greater solubility of the Mg compounds.

CA-SORPTION CURVES ON ELECTRODIALIZED SOIL COLLOIDS

The colloidal fractions of the six soils given in Table 1 were separated by standard methods and electrodialized in the usual manner. The Ca-sorption capacities of the six soil colloids were determined and the results are shown graphically in Figs. 7, 8, and 9. It is clearly evident that the end points of the titrations were obtained in these studies. It is of interest in this connection to contrast these curves equilibrated with Ca with those obtained with Na on several of the same soils as reported in a recent publication (1). The sorption capacity of the different soil colloids was characterized by their chemical composition in that a direct relationship was obtained with $SiO_2 = R_2O_3$ (Table 1). Several distinct breaks were obtained in the conductivity curves, the first of which might be attributed to changes in degrees of dispersion. The marked rise in the conductivity curves is due to the increase in conductivity of Ca colloids as compared with H colloids, but beyond the end point of the titration the conductivity of the suspensions decreases. The latter decrease is due both to flocculation of the colloids and to the common ion effect of the excess Ca depressing the dissociation of the Ca colloid. Originally the electrodialized colloids were flocculated, H colloids, but the first increments of Ca dispersed the clays which were again flocculated at the saturation point.

INFLUENCE OF CA ON THE SORPTION OF K

This study was made on the six soil colloids discussed above by adding a constant amount of KCl to the suspensions over the range o to 125% Ca saturation. The K was added in amounts equivalent to approximately 50% of the saturation capacity of the colloids. Since the results with all of the soil colloids were in general similar, only those for the Lufkin colloid are shown (Fig. 10). The K sorbed

TABLE 4.—*Amount of carbonates decomposed at 3½, 8, and 11 months in percentages of total amount applied.**

Rate of liming in percentage of Ca-sorption value	Soil types																	
	Cecil clay			Decatur clay loam			Hartsells sandy loam			Norfolk sandy loam			Delta very fine sandy loam			Lufkin clay		
	3½ months	8 months	11 months	3½ months	8 months	11 months	3½ months	8 months	11 months	3½ months	8 months	11 months	3½ months	8 months	11 months	3½ months	8 months	11 months
	Calcium Carbonate																	
25	100	—	—	92	95	99	76	91	100	81	96	99	73	85	88	100	—	—
50	83	91	96	87	93	97	78	91	98	78	89	95	67	72	90	97	98	99
75	72	84	90	79	89	91	76	82	85	76	82	95	—	—	—	85	93	96
100	61	66	74	68	76	84	71	74	77	73	80	90	47	47	59	70	75	83
	Calcium Carbonate and Magnesium Carbonate in Chemically Equivalent Amounts																	
25	88	95	100	83	92	100	80	94	100	69	99	100	63	85	85	96	98	100
50	85	90	95	84	90	95	81	92	100	84	95	99	70	75	89	92	96	98
75	75	85	91	83	90	94	84	92	97	71	91	97	45	53	78	84	93	97
100	73	80	86	73	82	90	75	80	83	76	88	94	47	50	60	67	74	77

*Calculated from free carbonate determination as follows: Amount carbonate applied—free residual carbonate = amount carbonate decomposed.

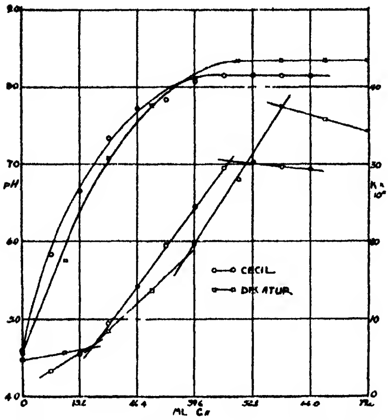

FIG. 7.—Air-$CaCO_3$-H-Clay equilibria, Cecil and Decatur.

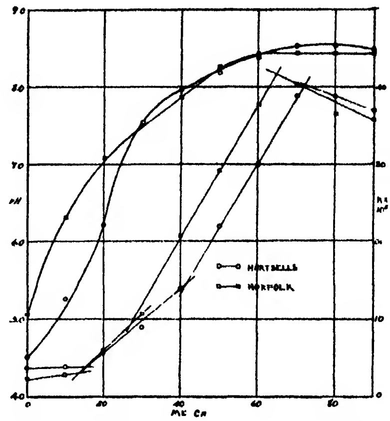

FIG. 8.—Air-$CaCO_3$-H-Clay equilibria, Hartsells and Norfolk.

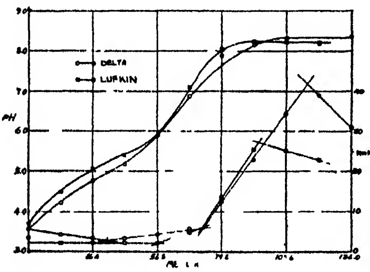

FIG. 9.—Air-$CaCO_3$-H-Clay equilibria, Delta and Lufkin.

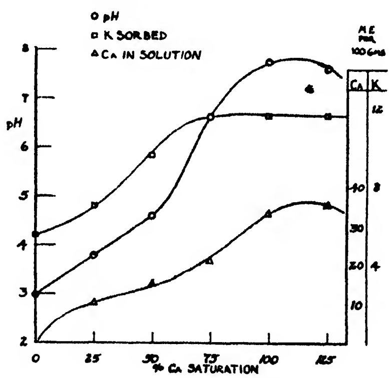

FIG. 10—The influence of $Ca(OH)_2$ on sorption of K by H-Lufkin colloid.

increased directly with degree of Ca saturation to the point of 75% saturation beyond which a constant amount was removed. These results are in accord with those of Peech and Bradfield (9), except that the percentage increase in K sorbed by Ca colloids over H colloids was not quite as marked in this study. The concentration of soluble Ca at the higher degrees of saturation probably repressed the further sorption of K.

INFLUENCE OF LIME ON NITRIFICATION OF AMMONIUM SULFATE AND THE WATER-SOLUBLE CALCIUM AND POTASSIUM IN SOILS

A Cecil clay and a Norfolk sandy loam of low fertility were selected for this study. The soils were set up in tumblers with increasing increments of $CaCO_3$, or a mixture of Ca and Mg carbonates, and

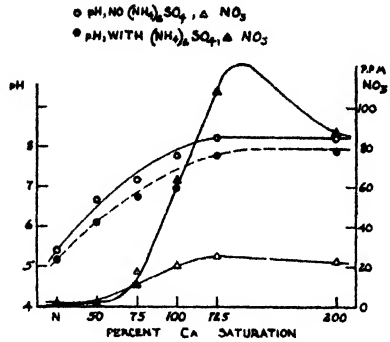

FIG. 11.—The influence of lime on the nitrification of $(NH_4)_2SO_4$.

incubated with and without $(NH_4)_2SO_4$ at 29° to 30° C for periods of 10 to 20 days. The procedure of this experiment was similar to that reported previously (8), except the lime was added to the soil in increments up to 150% and 200% of its Ca-sorption capacity in the case of Norfolk and Cecil soils, respectively.

It was found after 10 days with the Cecil soil that the most rapid nitrification occurred at 125% saturation with the calcic lime and at 200% saturation with the Ca.Mg lime as shown in Fig. 11 and Table 5, respectively. There was no nitrification of the added $(NH_4)_2SO_4$ at or below 50% saturation at 10 days. The nitrification of the native N was increased by lime up to 125% saturation. At the end of 20 days 85.5% of the added $(NH_4)_2SO_4$ was nitrified at 200% saturation and 95% at 100% saturation in the calcic and Ca.Mg-limed soils, respectively. The water-soluble K increased very slightly in the calcic-limed soils but increased greatly in the Ca.Mg-limed soils.

The results on the Norfolk soil are given in Table 6, and show no nitrification of $(NH_4)_2SO_4$ at 10 days. However, there was an increase in the H-ion concentration resulting from hydrolysis of the added $(NH_4)_2SO_4$. After 20 days incubation there was 20.4% and 63.5% of the added $(NH_4)_2SO_4$ nitrified in the 100% and 150% saturated soils, respectively. The water-soluble Ca and K were increased very greatly in the presence of $(NH_4)_2SO_4$ which was due to the solvent action of the acids formed. The pH values of the $(NH_4)_2SO_4$)-treated soils decreased considerably due to the presence of acids on this soil of low buffer capacity.

These results indicate that heavy liming enhances nitrification of $(NH_4)_2SO_4$, that Ca.Mg lime promotes more rapid nitrification, and that the native Ca and K are liberated during the process.

DISCUSSION

It was realized at the beginning of this investigation that a liming method was needed which would be applicable to widely different soils and crops. Moreover, it was desirable that the use of the method would give the optimum amount of lime needed as well as the amount that would cause liming injury. The $CaCO_3$ equilibration method was found to possess the features mentioned above. The method is not empirical but is based on the equilibrium point at constant concentration, temperature, and pressure. The range of degrees of base saturation and H-ion concentration is complete from that of the native soil to completely saturated soils. Further additions of liming materials simply act as a reserve in the soil.

TABLE 5.—*The influence of dolomitic lime on the nitrification of ammonium sulfate and the water-soluble calcium and potassium in Cecil clay soil, p.p.m. of air-dry soil.*

Ca.Mg added % saturation	10 days							20 days						
	No $(NH_4)_2SO_4$ added			200 p.p.m. N as $(NH_4)_2SO_4$ added				No $(NH)_2SO_4$ added			200 p.p.m. N as $(NH_4)_2SO_4$ added			
	NO_3	Ca	pH	NO_3	% of added N as NO_3	Ca	pH	NO_3	K	pH	NO_3	% of added N as NO_3	K	pH
None	2.5	5.0	5.30	1.4	—	33.8	5.18	2.5	21.0	5.00	1.5	—	20.0	4.85
50	4.7	15.0	6.50	1.9	—	58.0	6.06	13.7	23.8	6.12	11.2	—	25.0	5.93
75	18.8	39.5	6.90	35.0	8.15	98.0	6.25	27.5	23.8	6.55	108.5	40.5	42.5	5.70
100	22.5	64.0	7.65	100.0	38.7	196.0	6.35	30.0	13.7	7.50	220.0	95.0	32.5	6.07
125	25.5	79.0	7.95	98.0	36.3	190.0	7.04	40.0	15.0	7.77	212.0	86.0	35.0	6.50
200	25.0	75.0	8.28	156.0	65.5	270.0	7.91	40.0	22.5	8.25	167.5	63.8	30.0	7.82

TABLE 6.—*The influence of lime on the nitrification of ammonium sulfate and the water-soluble calcium and potassium in Norfolk sandy loam soil. p.p.m. of air-dry soil.*

Ca.Mg added % saturation	10 days							20 days						
	No $(NH_4)_2SO_4$ added			200 p.p.m. N as $(NH_4)_2SO_4$ added				No $(NH_4)_2SO_4$ added			200 p.p.m. N as $(NH_4)_2SO_4$ added			
	NO_3	Ca	pH	NO_3	% nitrified	Ca	pH	NO_3	K	pH	NO_3	% nitrified	K	pH
None	21.5	45.0	4.70	7.0	—	69.0	4.80	30.0	Tr.	4.60	10.6	—	2.50	4.70
50	15.0	39.0	5.40	5.0	—	97.0	5.39	18.7	1.56	5.50	6.2	—	3.76	5.05
75	16.2	53.0	5.98	8.2	—	120.0	5.50	13.3	1.88	5.90	11.2	—	4.07	5.00
100	16.8	57.0	6.70	13.2	—	165.0	5.90	16.9	2.50	6.60	57.6	20.4	—	5.00
150	21.2	90.0	7.95	20.5	—	265.0	7.40	22.5	3.44	7.90	150.0	63.5	6.90	6.82

Liming materials may be added in constant increments of any percentage of the saturation capacity of the soil; also, either calcic or dolomitic limestone may be used in chemically equivalent amounts. In this investigation lime was added in increments of 25% of the Ca sorbed by the soil, thus giving 4 points for obtaining buffer or yield curves. It would possibly be desirable to have another point where an excess of lime is added, but this can be varied to suit the limitations of the particular experiment concerned.

The $CaCO_3$ equilibration method appears to be especially desirable for studying the effect of base saturation and reaction on the distribution of ions in the soil and the effect of lime on the availability of plant nutrients and composition of plants. A study of these factors is now in progress and is to be reported soon.

SUMMARY

The results of this investigation may be briefly summarized as follows:

1. The calcium carbonate equilibration method of liming soils was found to offer desirable features for a comprehensive study of liming problems.
2. The amount of calcium sorbed from the added calcium carbonate at the point of equilibrium is termed "Ca-sorption value". The sum of the latter value and the native exchangeable Ca is termed "Ca-sorption capacity". The laboratory procedure is given for obtaining these values.
3. Increments of the "Ca-sorption capacity" of the soil are proposed for use as a lime requirement method. The results from this method were used with yield curves to obtain the optimum amounts of lime for soils and cropping systems.
4. The $CaCO_3$ equilibration method was shown to give complete titration curves with very definite end points on electrodialized soil colloids.
5. The value of this method for studying the effect of lime on the sorption of ions and on the biological activity in soils was indicated by studies on potash and nitrification.

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A CORRELATED STUDY OF THE INHERITANCE OF SEED SIZE AND BOTANICAL CHARACTERS IN THE FLAX CROSS, REDWING × OTTAWA 770B[1]

W. M. Myers[2]

THE value of seed flax as a cash crop has given impetus to the work of breeding improved varieties. Since the flax breeder is materially aided in his work by a knowledge of the genetical constitution of the material which he is using, it was considered desirable to obtain such information from a study of inheritance in a cross between two varieties, Redwing and Ottawa 770B, which are being used as parents in the flax breeding work at University Farm, St. Paul, Minn. Several investigators, including Johnson (9)[3] and Arny (1), have found a close association between seed size and percentage of oil, thus emphasizing the importance of size of seed in commercial varieties of flax. Consequently, a study of this character and its relation to the qualitative characters of the flax plant seemed of value.

LITERATURE REVIEW

The literature relating to the genetics of flax has been reviewed by Tammes (21, 22) in two recent papers; therefore, only the literature pertaining to the characters dealt with in this study will be reviewed here.

FLOWER COLOR

As a result of a series of investigations, Tammes (18, 19) demonstrated the existence of two basic genes, B and C, the presence of both of which was necessary for the production of color in the petals. Later, Kappert (10) found that Tammes' factor B actually consisted of two factors, B_1 and B_2. In the presence of these three basic flower color genes, designated as B_1, B_2, and C^1, Tammes (19) found the petal color to be pink. A factor, D, acting in the presence of these three genes produced a lilac color and another factor, F, in the presence of B_1, B_2, C^1, and D, conditioned the development of light blue petals. In the absence of D, F had no appreciable effect, but acting with D it caused a dilution of color in addition to changing lilac to light blue. Tammes (18) has reported, in addition, two genes, A and E, which modify the intensity of pink, lilac, or blue and an eighth flower color gene, K, which governs the distribution of color in the petals (21).

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Paper No. 1426 of the Journal Series, Minnesota Agricultural Experiment Station. Submitted to the faculty of the graduate school of the University of Minnesota in partial fulfillment of the requirements for the degree of master of science. Received for publication April 30, 1936.

[2]Instructor. The author wishes to express his appreciation to Prof. A. C. Arny for advice and aid during the course of the experiment and to Dr. L. R. Powers and Dr. H. K. Hayes for kindly suggestions and criticisms during the genetical analysis and preparation of the manuscript.

[3]Numbers in parenthesis refer to "Literature Cited", p. 634.

SEED COLOR

Tammes (20) has found that the seed coat is colored only if a basic factor, G, is present. Various combinations of the dominant and recessive condition of B_1 and D, the genes affecting flower color, acting with the basic factor G, lead to the development of modifications of seed colors and there are a further series of multiple factors which condition the intensity of color. Dependent upon various associations of these multiple factors and with G, B_1, and D also being present, there are a series of colors with a definite chestnut tone, ranging from dark yellow thru brownish yellow to dark brown. With D or both B_1 and D lacking, the color of the series is greyish brown instead of chestnut. In the presence of G and D, with B_1 absent, all except the lightest colored types have a greenish tone.

Blaringhem (2, 3), in crosses of brown-seeded types with types bearing white (*blanc ivoire*) seeds, obtained, in segregating populations, in one case brown- and white-seeded individuals in a 3:1 ratio and in another case a ratio approximating 15:1. Graham and Roy (6) found that dark brown color was produced by a factor, the absence of which causes a yellow brown color. If, in addition, another factor necessary for the production of flower color was lacking, the seed was yellow.

SMOOTH OR CILIATE FALSE SEPTA

In many types or varieties of flax the margins of the false septa in the boll are covered with hairs or cilia whereas in other types the margins are entirely smooth or free from hairs. Tammes (16) found that the two types were differentiated by a single factor pair for the production of cilia on the false septa and that hairiness was dominant. Blaringhem (2) has also reported ratios approximating 3:1, but in one case (3) obtained results more nearly approaching 15:1 for this character.

SEED SIZE

Tammes (16) has studied the inheritance of length and width of seed in a number of crosses. In all cases she found that the F_1 generation was intermediate and that seed size was dependent upon multiple factors, probably 4 or 5. In a later paper, Tammes (22) stated that probably 2, 3, or 4 factors were involved in the inheritance of length and width of seed.

MATERIALS AND METHODS

The material used in this study consisted of the parents, and the F_1, F_2, and F_3 generations of a cross between the varieties Redwing, C.I. 320, and Ottawa 770B, C.I. 355. Redwing has light blue flowers, small brown seeds, and cilia on the margins of the false septa. Ottawa 770B has white flowers with narrow inrolled petals, medium large yellow seed, larger than that produced by Redwing, and non-ciliate false septa.

An F_2 generation of this cross was grown during the summer of 1932, and F_1, F_2 and 100 F_3 lines were grown in 1933. The F_3 lines were from F_2 plants selected at random. Three replicated single row plats 6 feet long, of 25 seeds each, were planted in each F_3 line. The single-row plats were randomized within each replication and the parents were alternated every sixth and twelfth row to serve as checks.

The material was classified for blue vs. white petals, brown vs. yellow seeds, and ciliate vs. non-ciliate false septa. Seed size was determined by weighing 50 seeds from each plant and the weights were recorded to an accuracy of 5 milli-

grams. Throughout the remainder of this paper seed size will be given in milligrams per 50 seeds.

In analyzing the data, X^2 for goodness of fit has been used in determining the fit of observed ratios to the theoretical and values of P were taken from Fisher's (4) table of X^2. For tests of significance when the analysis of variance was used, F was calculated by dividing the larger mean square by the smaller mean square as described by Snedecor (15) and compared with the values of F for P of .05 and .01 obtained from Snedecor's table XXXV. Throughout the analysis, a value of P = .05 was taken as the lower level of significance.

EXPERIMENTAL RESULTS

PETAL COLOR

The segregation for petal color in F_2 is shown in Table 1.

TABLE 1.—*Segregation in the F_2 generation for blue vs. white petal color in a cross of Redwing×Ottawa 770B.*

Culture No.	Blue	White	White, %	X^{2}*
		1932		
1772	521	135	20.6	6.837
		1933		
271	54	12	18.2	1.636
272	53	18	25.4	0.005
275	62	9	12.7	5.751
276	63	14	18.2	1.909
280	60	14	18.9	1.459
Total X^2 for 1933				10.761
Total segregation for 1933	292	67	18.7	7.689

*For 5% level of significance, $X^2 = 3.841$ for 1 degree of freedom and $X^2 = 11.070$ for 5 degrees of freedom (Fisher, 4).

In 1932 the ratio of 521 blue to 135 white segregates approaches the 3:1 ratio which would be expected on the basis of a single factor difference. The x^2 value, however, gives a P of less than .01 (Fisher, 4), indicating that the deviation is greater than would be expected by chance, this deviation resulting from too few individuals in the recessive class.

A x^2 value was calculated for each of the five F_2 families grown in 1933 and the total x^2 obtained, following the method given by Fisher (4). P in this case lies between .05 and .10, the deviation from the theoretical ratio therefore not being statistically significant. One of these families, culture 272, shows an almost perfect fit to a 3:1 ratio, while in the remaining four families the deviation is in one direction, i.e., a deficiency of the recessive class. Apparently the number of individuals in each family is too small for the disturbance in the ratio to be detected by this test. However, the total ratio for 1933 of 292 blue to 67 white segregates gives a x^2 in excess of that expected for the 1% point.

A classification of the 100 F_2 plants on the basis of their breeding behavior in F_3 gave a ratio of 21 homozygous blue : 60 heterozygous

: 19 homozygous white plants. x^2 for fit to a 1:2:1 ratio gives a P between .10 and .20, the fit of observed to calculated being good.

On the basis of the hypothesis of a single factor pair difference, the ratio of blue to white petaled plants in each segregating F_3 family should be approximately 3:1. x^2 was calculated for each family and these x^2 values added giving a total x^2 of 132.68 with n = 60. Applying the formula $\sqrt{2x^2} - \sqrt{2n-1}$ given by Fisher (4), the normal deviate is found to be 5.39 ± 1 showing that the deviation from the expected ratio is highly significant. In only 7 of the 60 segregating lines does the percentage of plants with white petals equal or exceed the theoretical 25%, while the remaining 53 lines show varying degrees of deficiency in the recessive class. A total of all the segregates in each class for the 60 F_3 families gives a ratio of 2,676 blue- to 591 white-flowered plants. x^2 in this case is 83.20, the deviation again being highly significant.

These results indicate that the varieties studied here probably differ by a single factor pair for the production of color in the petals but it is also established that there is a deficiency in the recessive class which is too great to be explained on the basis of random sampling. This deficit of white blossomed individuals can be estimated by comparing the number in the recessive class with the expected on the basis of a 3:1 ratio. On this basis the number of white-petaled plants in F_3 should be 892. Actually only 591 white segregates were obtained, leaving 33.8% of the possible number which failed to reach the flowering stage.

Tammes (17, 18) and Kappert (10,11) have reported a similar deficiency of white-flowered segregates in crosses involving the basic gene B_1. This deviation from expected was explained by Tammes (17) as resulting from a lower viability of the homozygous white zygotes. She found that fewer mature seeds per boll were produced by white-flowered segregates and also that the seed of the white individuals was lower in germination. Tammes (18) attributed this lower viability of homozygous white zygotes to a semi-lethal effect of C' which was expressed only in the absence of B_1. Kappert (11), on the other hand, concluded that there was a different degree of "konkurrenzfahigkiet der Gameten" so that more female gametes of the type B_1 B_2, C' were formed than of the type b_1 B_2 C'. He (11) also reported that the deficiency could not be due to a semi-lethal action of the C' gene, but rather that it was caused by some other gene or genes contributed by the blue-flowered parent.

If a lower viability of the homozygous white zygotes is to explain the deficiency in the recessive class in this study, the homozygous white F_3 families should have a significantly lower mean number of plants per row at the time when the plants are in bloom than either the homozygous blue or segregating families. The mean number of plants per row for the three classes were: pure blue = 18.08 ± .41, segregating = 18.35 ± .24, and pure white = 14.12 ± .43. A comparison of the means for the pure blue and segregating families with the mean of the white families by use of standard error of the differences gives a D/S.E. of 6.66 and 8.58, respectively. The pure white families, therefore, had significantly fewer plants per row than either

the pure blue or segregating lines, despite the fact that the same number of seeds were planted in each case and that these families were all distributed at random in the same replications.

On the basis of the mean number of flowering plants in the F_3 families, the pure white seeds produced only 78.1% as many flowering plants as did the homozygous blue families. A similar comparison of homozygous white with segregating families shows that pure white seeds produced only 77.0% as many flowering plants as did the seed of heterozygous plants. If the same relative proportion of the white-flowering plants are lost in segregating populations due to this lower viability, then this factor would account for 21.9% to 23.0% of the recessive class. The previous calculation, based upon the numbers obtained in the 60 segregating F_3 families, showed that 33.8% of the possible white-petaled plants failed to reach the flowering stage. Therefore, on the basis of these calculations, 11.9% or 10.8%, respectively, of the recessive segregates remain unaccounted for and no evidence was available in this study bearing directly upon the cause of this remaining deficiency.

A comparison of the plant survival in the Redwing and Ottawa 770B check rows should produce some information regarding the factorial explanation of the 21.9% lower viability of the homozygous white-flowered F_3 families. Thirty-six rows of each parental variety were available and the number of plants per row was compared by an analysis of variance. The value of F in comparing mean square for varieties with mean square for error was 32.1, while F for the 1% point with appropriate degrees of freedom is 7.01. The mean number of plants per row for Redwing was 15.7 and for Ottawa 770B 12.0, 23.6% less of the seeds of the white-flowered variety producing flowering plants. The value is very close to the 21.9% and 23.0% obtained when a similar comparison was made between blue and heterozygous families, respectively, and the white-flowered families in F_3, differing by only 1.7% and 0.6%.

The reduced viability of recessive segregates in this cross may be caused by (a) a semi-lethal action of the recessive petal color gene, (b) a semi-lethal gene or genes carried by both parents and acting only in the presence of the recessive petal color condition or (c) a semi-lethal gene or genes closely linked to the recessive petal color gene. No evidence was available in the present study for determining which of these explanations is correct.

SEED COLOR

All blue-flowered segregates obtained in this study produced brown seed and all white-flowered segregates produced yellow seed. These results may be explained by the assumption that the production of color in the flower and in the seed coat is dependent upon the same factor pair or upon two genes so closely linked that no observed crossovers occurred.

SMOOTH OR CILIATE FALSE SEPTA

The degree of hairiness of the false septa of the F_1 plants was distinctly intermediate between the parents. In the F_2 generation, intermediate types were obtained varying from a trace of cilia to those that were hardly distinguishable from the homozygous condition. Although this variation indicated that modifying factors might be present, no satisfactory classification could be made within the intermediate types. Consequently, all segregates were placed in one of three classes, i.e., completely ciliate, intermediate, or smooth. The segregation in F_2 for both years is given in Table 2.

In 1932, X^2 for fit to a 1:2:1 ratio gave P between .02 and .05, thus falling somewhat below the level which has been selected as significant. X^2 was calculated for each of the five families in 1933 and the total X^2 was less than that for the 5% point with 10 degrees of freedom. Since it was found in the analysis of flower color that this total X^2 is subject to error due to the small number of plants in each family, if the deviation is predominately in one direction, the total number of segregates in each class for 1933 was obtained. X^2 for fit to a 1:2:1 ratio gave P between .01 and .02. Since difficulty was encountered in a few cases in distinguishing between completely ciliate and intermediate segregates, such errors might account for these deviations in F_2. Combining the completely ciliate and intermediate classes, X^2 for fit to a 3:1 ratio for 1932 gave P between .05 and .10, while for 1933 P was between .01 and .02, again falling below the level selected as significant.

TABLE 2.—*Segregation in F_2 for ciliate, intermediate, and non-ciliate false septa in a cross of Redwing×Ottawa 770B.*

Culture No.	Class*			X^2 for fit to 1:2:1†
	SS	Ss	ss	
		1932		
1772	149	362	145	7.008
		1933		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
272	26	30	15	5.113
275	18	37	16	0.239
276	20	44	13	2.844
280	20	42	12	3.081
Total X^2 for 1933				14.853
Total segregation for 1933	107	183	69	8.181

*The symbol S from the recessive condition smooth has been used to designate the gene for the production of cilia on the false septa.
†For 5% level of significance (Fisher, 4), X^2 = 5.991 for n = 2 and X^2 = 18.307 for n = 10.

The genotypes of the 100 random selected F_2 plants, determined from their breeding behavior in F_3, were in the ratio of 23 homozygous ciliate : 52 heterozygous : 25 homozygous smooth, giving P between .80 and .90. Of these 100 F_2 plants, three which were classified as intermediate in F_2 bred true in F_3 and one which had been classified

as completely ciliate in F_2 segregated in F_3. From this it is seen that classification of the two genotypes, homozygous ciliate and heterozygous, on the basis of the phenotype is subject to some error. X_2 for fit to a 1:2:1 ratio was calculated for each of the 52 segregating F_3 families. Total X_2 was 105.08 and n = 104. Applying the formula given by Fisher (4), the normal deviate is .10 ± 1.0, the fit to a 1:2:1 ratio being good. When all of the individuals in each class for the 52 families are considered, the ratio is 697 ciliate : 1,284 intermediate : 696 smooth which fits a 1:2:1 ratio very well.

From the results obtained in F_3, it may be concluded that presence or absence of cilia is dependent upon a single factor pair in this cross. Consequently, the deviations in F_2, although large, probably may be considered as chance deviates which are occasionally expected due to the errors of random sampling.

INDEPENDENCE OF INHERITANCE OF PETAL COLOR AND CILIATE CHARACTER

Determination of the presence or absence of linkage between the two genes for the production of color in the petals and production of cilia on the false septa, respectively, was made by use of X^2 for independence as given by Fisher (4). These results in F_2 are presented in Table 3.

TABLE 3.—*X^2 for independence of petal color and ciliate character.*

Year	Blue ciliate	Blue smooth	White ciliate	White smooth	X^2 for independence*
1932	409	112	102	33	0.541
1933	234	58	56	11	0.417

*For 5% level of significance (Fisher, 4) X^2 = 3.841 for n = 1.

In 1932, P was just less than .50 and in 1933 slightly in excess of .50. Therefore, no evidence of linkage was obtained in either year.

SEED SIZE

Before attempting a study of the inheritance of seed size it was considered desirable to determine the effect of environmental factors upon the character so far as this study was concerned. Thirty-six rows of each parent were distributed through the three replications of the F_3 families and from each row five plants were selected at random for the determination of seed size. An analysis of variance, presented in Table 4, was calculated for each variety.

Comparing the variance between rows with the variance within rows by means of F gave in each case a P of less than .01, indicating significant differences in seed size in different rows.

PARTIAL DOMINANCE OF LARGE SEED SIZE

A frequency distribution for weight per 50 seeds of individual plants of parents, F_1, and F_2 are presented in Table 5 and these data are summarized in Table 6.

TABLE 4.—*Analysis of variance of weights per 50 seeds in milligrams of individual plants of Ottawa 770B and Redwing grown as checks with the F_3 generation.**

Variation	D.F.	Mean square	F	Value of F for 1% point
		Ottawa 770B		
Between rows	35	354.8049	5.44	1.92
Within rows	144	65.2083	—	—
		Redwing		
Between rows	35	199.1425	2.42	1.92
Within rows	144	82.3611	—	—

*Mean seed weight of Ottawa 770B = 270.3 and Redwing = 204.7.

TABLE 5.—*Frequency distribution of weights in milligrams of 50 seeds for individual plants of parents, F_1, and F_2.*

Class	170	185	200	215	230	245	260	275	290	305
Redwing (1933)	—	—	2	39	40	1	—	—	—	—
Ottawa 770B (1933)	—	—	—	—	—	—	15	26	4	—
F_1 (1933)	—	—	—	—	—	1	7	6	—	—
F_2 (1933)	1	1	3	5	48	76	142	67	15	1
F_2 (1932)	2	4	39	94	218	147	91	13	2	—

TABLE 6.—*Mean weight in milligrams per 50 seeds and variance of parents, F_1, and F_2.*

	Number of plants	Mean weight in mg.	Variance
Redwing	82	216.59	58.57
Ottawa 770B	45	267.44	76.84
F_1 (1933)	14	257.14	79.67
F_2 (1933)	359	250.35	327.32
F_2 (1932)	610	229.40	325.79

The parents used in this comparison are from the check rows interspersed among the F_1 and F_2 rows. Class intervals of 15 milligrams were used in the frequency distribution since this value is equal to approximately two times the standard deviation of the parents. From Table 5 it is seen that the distribution in F_1 more nearly approaches the distribution of Ottawa 770B than of Redwing. This can be more clearly shown by a comparison of the means. The mean of the F_1 plants (257.14) is 40.55 mg higher than the mean of Redwing and only 10.30 mg lower than the mean of Ottawa 770B. In addition, the mean of the F_2 grown in 1933 (250.35) approaches more closely the mean of Ottawa 770B than of Redwing.

Fisher, Immer, and Tedin (5) have pointed out that a correlation of the means of F_3 families with the variance of those families furnishes evidence of the presence of dominance. In calculating the variance of each F_3 family, the variance between rows was removed, since the variability within rows should more clearly represent the

true variance of the family. A correlation coefficient of .276 was obtained, the F_3 lines with the larger mean being the more variable, and this gives a P of less than .01 (Fisher, 4, Table VA). Therefore, although the correlation coefficient is not large, it supports the evidence of partial dominance of large seed size given by the means of the F_1 and F_2 generations.

SEGREGATION FOR SEED SIZE

The variance of the parents, F_1, and F_2 generations may be obtained from Table 6. Here it is seen that the variance of Ottawa 770B is greater than that of Redwing, an opposite relation to that found for the check rows grown with the F_3 families (Table 4). Since the number of plants of each variety is small, no statistical significance can be attached to this difference in variance. The variance of the F_1, based on 14 plants, is 79.67, a value similar to the variance of the two parents.

Since the parental material presented in Table 5 was grown in 1933, a logical comparison can be made only with the F_2 generation grown the same year. The distribution of the 359 F_2 plants extends beyond both extremes of the two parents, two plants with seeds smaller than the smallest deviate in Redwing and one plant with seeds larger than the largest seeded plant of Ottawa 770B being obtained. In view of the comparatively small number of parent plants it is probable that these three plants could be chance deviates and, therefore, it can not be concluded that transgressive segregation has occurred. It does appear, however, that some plants of each parental type have been recovered.

Since it has previously been shown that large seed size is partially dominant, the smaller seeded segregates which approach the phenotype of Redwing should be more nearly homozygous than those segregates which approach the mean of Ottawa 770B. From Table 5 it can be determined that 10 of the 359 F_2 segregates have seed weights as low or lower than the mean of Redwing. By chance an equal number of such segregates should fluctuate on the other side of the mean of Redwing, provided such segregates are actually of the same genotype as regards major factors for seed size. If this is true, 20 plants, or a proportion of 1 out of 18 of the segregates, are of the same phenotype as Redwing. These results could be explained on the basis that two, or perhaps three, major factors are determining seed size.

The mean weight per 50 seeds and the variance of each of the 100 F_3 families are presented in Table 7.

The lower limit of the first class of variances was taken as 74 since that is the average of the parental material grown as checks with the F_3 families. The size of the intervals was calculated so that a comparison of the obtained variances with 74 gives a "Z" (Fisher, 4) of 0–1, 1–2, 2–3, 3–4, 4–5, and 5–6 times its standard error. Since the number of plants per family is not constant, an n of 50, the average degrees of freedom for the F_3 families, was used in calculating the standard error of "Z".

TABLE 7.—*Contingency table of means and variances for weight of 50 seeds per plant in milligrams for 100 F_3 families.*

Z/S.E.	Variance	Mean seedweight, mg*									Total
		196 to 205	206 to 215	216 to 225	226 to 235	236 to 245	246 to 255	256 to 265	266 to 275	276 to 285	
0–1	74–99	–	–	–	2	–	–	1	–	–	3
1–2	100–132	–	–	4	5	6	2	1	–	–	18
2–3	133–175	–	2	–	14	5	9	1	–	–	31
3–4	176–232	–	–	2	4	9	7	1	–	–	23
4–5	233–308	–	–	1	2	8	6	–	1	–	18
5–6	309–409	–	–	–	–	4	2	–	–	1	7
Total		–	2	7	27	32	26	4	1	1	100

*Mean seed weight of Redwing = 204.7 and Ottawa 770B = 270.3.

Only three of the 100 F_3 families had variances falling in the first group, i.e., with Z/S.E. of 0–1. The means of these families are more or less intermediate, although one family has a mean falling in the group from 256–265. However, the actual mean of this line is 256 and it is therefore probably not a chance deviate from the genotype of Ottawa 770B. In addition to these three families, 18 families had variances which differed from 74 with Z/S.E. of two or less. The means of these families are also all intermediate between the parental means.

The mean weight of one F_3 line was 268 mg, which is not greatly different from 270.3 mg, the mean of Ottawa 770B. The variance of this family is 265 and a comparison of this variance with 74 gives Z/S.E. between 4 and 5. Therefore, although this family might be considered equal to Ottawa 770B in regard to mean size, it is still segregating and consequently is not the same genotype. Another F_3 family had a mean weight of 279 mg, a value somewhat, although perhaps not significantly, higher than Ottawa 770B. The variance of this family falls in the group with Z/S.E. of 5–6 and it is, therefore, also segregating for seed size.

No F_3 lines were obtained with a mean weight equal to or lower than that of Redwing. However, the means of two lines fall in the class 206 to 215, while the mean of Redwing is 204.7 mg. The actual mean of one of these families is 209 mg, a value not greatly different from the mean of Redwing. The variance of this family is 139, a value slightly higher than 132, which, when compared with the variance of the parents, gives a Z/S.E. of 2. Therefore, this single family might be regarded as a nearly homozygous line with the seed size of Redwing although the evidence is not conclusive. It has been previously pointed out that the results in F_2 could be explained on the basis of two, or perhaps three, major factors for seed size. On the assumption of three major factors, 1.6 lines of each parental type would be expected in 100 F_3 lines. Actually, with one doubtful exception, no pure breeding lines of either parental type were recovered from the 100 families studied. As a result, no definite conclusions regarding the number of major factors can be drawn, although

though it seems probable that more than three such genes were involved.

In a breeding program, the value of selecting for any given character depends partially upon the portion of the variance of that character which is heritable. This portion of heritable variance may be estimated from the correlation of measurements of related individuals. To determine this, the weight per 50 seeds of the F_2 plants was correlated with the mean weight per 50 seeds of their F_3 progenies and a correlation coefficient of .684 was obtained.

INDEPENDENCE OF INHERITANCE OF GENES FOR SEED SIZE AND GENES FOR THE PRODUCTION OF PETAL COLOR AND CILIA

The study of multiple factors by means of linkage of major size genes with known qualitative genes has been reported by Sax (14), Griffee (7), Immer (8), Lindstrom (12, 13), and others. It has already been demonstrated that two independently inherited qualitative genes are segregating in this cross. The presence or absence of linkage of major seed size genes with either of the two qualitative genes was determined by means of χ^2 for independence, using the F_2 data for 1932 and 1933. These data are presented in Table 8.

TABLE 8.—*X^2 for independence to test the presence or absence of linkage of major seed size genes with the genes for petal color and production of cilia, respectively.*

Year	D/F	X^2	P lies between
	Blue vs. White		
1932	4	7.139	.10 and .20
1933	2	1.101	.50 and .70
	Ciliate vs. Smooth		
1932	3	2.096	.50 and .70
1933	2	5.016	.05 and .10

In all cases P was above .05, indicating that no major seed size gene was linked with either qualitative gene in this material.

SUMMARY

The purpose of this study was to determine the mode of inheritance of petal color, seed color, cilia on the false septa of the bolls, and seed size.

White petal color behaved as a simple Mendelian recessive to blue, although a deficiency occurred in the recessive class which was too great to be attributed to chance. It was calculated that 33.8% of the possible white-flowered segregates failed to reach the flowering stage. Lower viability of the mature seed, or of the plants before flowering, or of both could account for a deficit of 21.9% of the recessive plants. No data were available for determining the cause of the remaining deficit.

The production of color in the seed coat was dependent upon the same gene which determined the production of color in the petals or upon a gene closely linked with the flower color gene.

The two varieties were differentiated by a single factor pair with intermediate dominance for the production of cilia on the false septa. This gene was inherited independently of the petal color gene.

Seed size was dependent upon multiple factors. The number of factors could not be determined, although segregates of both parental types were obtained among 359 F_2 plants. Large seed size was partially dominant over small. A correlation coefficient of .684 was obtained between the weight per 50 seeds of the F_2 plants and the mean weight of their F_3 progeny.

No linkage could be demonstrated between major seed size genes and the genes responsible for petal color and cilia on the false septa.

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LEAF NUMBER OF SORGHUM STALKS[1]

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THE number of leaves of vegetatively mature stalks of cultivated sorghum (*Sorghum vulgare* Pers.) frequently has been determined and is regarded as a varietal character. The number varies with date of planting, locality, and season as well as with variety, which demonstrates that it also is influenced by environment.[3] As in all grasses, each node of a sorghum stalk produces a leaf, the number of leaves and nodes being identical. The leaves are counted more easily than are the nodes. It is commonly recognized that the first few small leaves die and dry up before the stalk reaches maturity, although in reporting leaf counts of mature stalks investigators usually ignore these first 10 leaves (more or less) borne on the nodes in the crown of the plant. It is obvious that such counts are lacking in exactness. The number of leaves and nodes is not definitely fixed in the embryo and variations in node number are observed between plantings on different dates from seed from the same selfed heads and between tillers and main stalks on the same plant. Consequently, it is not possible to obtain pure lines with a specific number of leaves under all environments.

Leafiness is an important character in sorghums used for forage. For some years sorghum workers have observed that early-maturing sorghums are characterized by fewer leaves, smaller leaves, and more slender stalks than are late-maturing varieties. The present investigation to determine the exact number of leaves produced by different sorghums under varying environments was undertaken to provide a better basis for future studies of the genetics and the physiological inter-relationships of leaf number.

The number of leaves on the main stem of maize varieties has been used as an index of length of growing period by Kuleshov[4], and Davidowicz[5] found a correlation between leaf number and earliness in tobacco.

METHODS

The data reported here were obtained at the United States Southern Great Plains Field Station at Woodward, Okla. All final leaf counts were made after the top, or flag, leaf appeared or after heading, and the counts included all leaves produced by a stalk. In order to facilitate the counting, the fifth leaf was cut off at an angle close to the stem two or three weeks after the seedlings emerged and later the tenth leaf was punched near the base at one side of the mid-rib. If the tenth leaf died or the number of leaves exceeded 20, it usually was found advisable also to mark the fifteenth, twentieth, or even the twenty-fifth leaf

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by using ticket punches having different shaped dies. In 1932, counts were made on 50 or more plants of each variety planted on June 23 in guard rows from individual selfed heads. In 1933, the counts again were made in guard rows planted from selfed heads, and the seed heads were obtained from plants of known leaf number when available. The season of 1933 was very unfavorable, owing to dry soil when the varieties were planted on June 14. Part of the seeds germinated within a week, but a considerable proportion did not emerge until July 19 after a rain. In three varieties leaf counts were made on plants which emerged July 19, in addition to those which emerged normally on June 20.

In 1934, a selfed head of each variety, from a plant of known leaf number, was divided into three parts and each part planted on a different date. The season of 1934 was very unfavorable and leaf counts could not be obtained on all varieties or dates of planting. Data were obtained, however, on all three plantings of four of the shorter-season varieties that matured sufficiently in the late plantings.

In 1934, the number of leaves and the date of first blooming were recorded also for the 207 plants in an F_3 progeny row from a selfed F_2 head of a cross between two very early sorghums, Dwarf Freed and an early dwarf feterita.

RESULTS OBTAINED

The frequency distribution of the total number of leaves on the main stalk of 18 varieties of grain sorghum grown in 1932 and 1933 is shown in Table 1. These varieties averaged from about 18 to approximately 27 leaves per stalk. The number on individual stalks varied over a range of 5 to 10 leaves per stalk for a single variety in the same season despite the fact that seed from selfed heads was used for planting. Some varieties, particularly darso and the milos, showed very little difference in the average number of leaves in the two seasons. The kafir varieties, however, showed average seasonal differences ranging from 1.1 to 3.2 leaves per stalk.

The effect of date of emergence or planting upon the number of leaves per stalk in 1933 and 1934 is shown in Table 2. Average differences within a variety in the same season ranged from 2.7 to 3.8 leaves per stalk for two dates of emergence in three varieties planted on June 14, 1933, and from 1.1 to 2.8 leaves per stalk for three dates of planting of four varieties in 1934. With the exception of the June 15 planting of feterita in 1934 that produced a thin stand there was a definite trend towards fewer leaves from the later emergence or planting. Wheatland milo appeared to have less variation than the other varieties in these two experiments and it also showed a minimum seasonal variation in results presented in Table 1. The data available show that total leaf number is determined both by variety and environment.

Table 3 shows the average number of leaves per stalk, the number of days in the vegetative period (emergence to heading), and the average number of days per leaf in the vegetative period for certain grain sorghum varieties in 1932 and 1933. The days per leaf, calculated by dividing the number of days in the vegetative period by the number of leaves, varied from 2.8 to 3.5. The two varieties of feterita, however, averaged slightly under 3 days per leaf in the two years observed and possibly they may possess a varietal difference of value in breeding leafy, short-season sorghums. All other varieties

TABLE 1.—*Frequency distribution of the number of leaves per main stalk of sorghum varieties in 1932 and 1933.*

Variety	Year	Classes for number of leaves for main stalks																	Mean leaves per stalk
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Dwarf milo	1932	—	—	—	—	—	—	—	1	9	31	20	2	—	—	—	—	—	24.2
Dwarf milo	1933	—	—	—	—	1	1	10	21	46	46	21	—	—	—	—	—	—	23.3
Beaver milo	1932	—	—	—	—	1	—	5	12	19	13	2	—	—	—	—	—	—	22.8
Beaver milo	1933	—	—	1	—	5	8	18	28	32	29	9	—	—	—	—	—	—	22.5
Wheatland milo	1932	—	2	7	29	18	2	1	—	—	—	—	—	—	—	—	—	—	18.2
Wheatland milo	1933	2	10	33	53	55	19	5	—	—	—	—	—	—	—	—	—	—	18.3
Fargo milo	1932	—	—	—	—	—	—	1	4	16	25	14	2	1	—	—	—	—	23.9
Fargo milo	1933	—	—	—	—	—	—	1	5	10	22	28	11	2	1	—	—	—	24.5
Feterita	1932	—	1	—	6	22	15	7	—	—	—	—	—	—	—	—	—	—	19.4
Feterita	1933	—	1	1	3	11	26	35	17	5	1	—	—	—	—	—	—	—	20.6
Spur feterita	1932	—	—	1	—	—	1	6	9	15	14	7	—	1	—	—	—	—	23.0
Spur feterita	1933	—	—	—	—	—	—	1	3	4	20	36	21	17	—	—	—	—	25.1
Dwarf hegari	1932	—	—	—	—	—	—	—	—	7	2	3	16	18	12	—	—	—	26.2
Dwarf hegari	1933	—	—	—	—	—	—	—	1	4	7	3	20	19	25	23	14	3	27.5
Ajax	1932	—	—	—	—	—	5	13	15	16	9	3	—	—	—	—	—	—	22.3
Ajax	1933	—	—	—	—	—	1	4	16	30	29	27	5	1	—	—	—	—	23.7
Chiltex	1932	—	—	—	3	22	29	16	3	—	—	—	—	—	—	—	—	—	19.9
Chiltex	1933	—	—	—	—	—	3	26	62	42	12	—	—	—	—	—	—	—	22.2
Early Red kafir	1932	—	—	1	8	9	16	9	2	—	—	—	—	—	—	—	—	—	19.7
Early Red kafir	1933	—	—	—	—	—	3	7	9	22	17	4	—	—	—	—	—	—	22.9
Dawn kafir	1932	—	—	—	2	19	25	10	2	—	—	—	—	—	—	—	—	—	19.8
Dawn kafir	1933	—	—	—	—	3	14	40	40	40	6	—	—	—	—	—	—	—	21.8
Sunrise kafir	1932	—	—	2	4	21	21	12	7	—	—	—	—	—	—	—	—	—	19.9
Sunrise kafir	1933	—	—	—	—	—	10	45	51	40	6	—	—	—	—	—	—	—	21.9
Reed kafir	1932	—	—	—	—	13	23	21	1	3	—	—	—	—	—	—	—	—	20.3
Reed kafir	1933	—	—	—	—	—	1	4	19	40	39	16	1	—	—	—	—	—	23.4
Sharon kafir	1932	—	—	—	5	10	29	8	5	5	1	1	—	—	—	—	—	—	20.3
Sharon kafir	1933	—	—	—	—	1	8	23	48	27	8	1	—	—	—	—	—	—	22.0
Standard kafir	1932	—	—	—	—	—	1	6	15	18	9	3	—	—	—	—	—	—	22.7
Standard kafir	1933	—	—	—	—	—	1	4	14	26	29	21	10	1	—	—	—	—	23.8
Bishop kafir	1932	—	—	—	—	—	1	1	22	16	8	2	—	—	—	—	—	—	22.7
Bishop kafir	1933	—	—	—	—	—	1	4	10	16	31	30	24	18	4	—	—	—	24.7
Darso	1932	—	—	4	11	22	29	3	—	—	—	—	—	—	—	—	—	—	19.2
Darso	1933	—	—	11	42	79	47	21	7	4	—	—	—	—	—	—	—	—	19.3
Grohoma	1932	—	—	—	—	—	1	8	18	14	11	—	—	—	—	—	—	—	22.5
Grohoma	1933	—	—	—	—	—	—	3	4	28	32	56	20	18	2	—	—	—	24.7

TABLE 2.—*Frequency distribution of number of leaves per stalk of sorghums from different dates of emergence in 1933 and different dates of planting in 1934.*

Variety	Year	Date of emergence or planting	Classes for number of leaves for main stalks															Mean leaves per stalk
			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Dwarf milo	1933	June 20	—	—	—	—	—	—	1	1	10	21	46	46	21	—	—	23.3
Dwarf milo	1933	July 19	—	—	1	—	4	10	9	12	12	3	—	—	—	—	—	19.5
Wheatland milo	1933	June 20	—	—	2	10	33	53	55	19	5	—	—	—	—	—	—	18.3
Wheatland milo	1933	July 19	1	4	14	22	4	2	—	—	—	—	—	—	—	—	—	15.6
Standard kafir	1933	June 20	—	—	—	—	—	—	—	1	4	14	26	29	21	10	1	23.8
Standard kafir	1933	July 19	—	—	—	—	—	—	9	14	16	2	—	—	—	—	—	20.3
Wheatland milo	1934	June 1	—	—	—	—	3	20	26	19	2	—	—	—	—	—	—	19.0
Wheatland milo	1934	June 15	—	—	—	1	5	21	39	20	3	—	—	—	—	—	—	18.9
Wheatland milo	1934	June 29	—	—	—	2	26	49	14	3	—	—	—	—	—	—	—	17.9
Feterita	1934	June 1	—	—	—	—	—	8	30	33	6	1	—	—	—	—	—	19.5
Feterita	1934	June 15	—	—	—	—	—	2	1	6	2	2	5	2	2	*	—	21.5
Feterita	1934	June 29	—	—	—	—	6	28	48	11	—	—	—	—	—	—	—	18.7
Darso	1934	June 1	—	—	—	—	—	—	—	4	33	39	7	—	—	—	—	21.6
Darso	1934	June 15	—	—	—	—	—	1	14	17	16	8	—	—	—	—	—	20.3
Darso	1934	June 29	—	—	—	—	2	13	24	7	1	—	—	—	—	—	—	18.8
Sooner milo	1934	June 1	—	—	—	2	34	55	7	1	—	—	—	—	—	—	—	17.7
Sooner milo	1934	June 15	—	—	—	14	13	14	2	—	—	—	—	—	—	—	—	17.1
Sooner milo	1934	June 29	—	—	21	50	22	1	—	—	—	—	—	—	—	—	—	16.0

*The June 15 planting of feterita was a thin stand compared with the other plantings, the thin stand causing increased vegetative growth and more leaves.

TABLE 3.—*Days in vegetative period and number of leaves per main stalk of sorghums grown in 1932 and 1933.*

Variety	C. I. No.	1932			1933			Two-year average		
		Days emergence to heading	Av. no. leaves per stalk	Days per leaf	Days emergence to heading	Av. no. leaves per stalk	Days per leaf	Days emergence to heading	Av. no. leaves per stalk	Days per leaf
Dwarf milo	332	73	24.2	3.0	71	23.3	3.1	72	23.8	3.1
Beaver milo	871	72	22.8	3.2	75	22.5	3.3	74	22.7	3.1
Wheatland milo	918	61	18.2	3.4	62	18.3	3.4	62	18.3	3.4
Fargo milo	809	81	23.9	3.4	83	24.5	3.4	82	24.2	3.4
Feterita	182	51	19.4	2.6	61	20.6	3.0	56	20.0	2.8
Spur feterita	623	66	23.0	2.9	69	25.1	2.8	68	24.1	2.9
Dwarf hegari	750	85	26.2	3.2	95	27.5	3.5	90	26.9	3.4
Ajax	968	74	22.3	3.3	82	23.7	3.5	78	22.5	3.4
Chiltex	874	65	19.9	3.3	70	22.2	3.2	68	21.0	3.3
Club kafir	901	—	—	—	71	22.1	3.2	—	—	—
Early Red kafir	866	68	19.7	3.5	71	22.9	3.1	70	21.3	3.3
Dawn kafir	340	68	19.8	3.4	76	21.8	3.5	72	20.8	3.5
Sunrise kafir	472	67	19.9	3.4	75	21.9	3.4	71	20.9	3.4
Reed kafir	628	66	20.3	3.3	72	23.4	3.1	69	21.9	3.2
Hydro kafir	1,023	—	—	—	82	23.3	3.5	—	—	—
Sharon kafir	813	68	20.3	3.4	78	22.0	3.6	73	21.2	3.5
Standard kafir	71	75	22.7	3.3	82	23.8	3.5	79	23.3	3.4
Bishop kafir	814	75	22.7	3.3	82	24.7	3.3	79	23.7	3.3
Darso	615	59	19.2	3.1	64	19.3	3.3	62	19.3	3.2
Grohoma	920	74	22.5	3.3	80	24.7	3.2	77	23.6	3.3
Sooner milo	917	—	—	—	52	15.9	3.3	—	—	—

averaged from 3.1 to 3.5 days per leaf. These results seem to be very consistent and indicate a close relationship between leaf number and vegetative period, approximating 3.3 days per leaf for all sorghum varieties under the conditions of the experiments. The close relationship between leaf number and vegetative period is further indicated by the correlation coefficient of $r = 0.853 \pm 0.029$ between these characters for the 39 varietal determinations listed in Table 3.

In the 207 plants of the F_3 progeny rows of the cross between Dwarf Freed sorgo and an early dwarf feterita, the number of leaves ranged from 8 to 20 and the number of days from emergence to first blooming varied from 25 to 50. The correlation coefficient for these two characters is 0.836 ± 0.014.

Data have been obtained upon the inheritance of leaf number in the above and other crosses. Publication of the results is being deferred, however, until more crosses are studied so that a more or less satisfactory genetic interpretation can be suggested. Results from a more favorable season are also desired.

DISCUSSION

The number of leaves, or nodes, of sorghums is shown to depend for its expression on both heritable and environmental factors. The range in number of leaves per stalk for sorghum varieties is heritable and in general determines the vegetative limits of the variety. Environment, chiefly differences in photoperiodism and temperature, alters the expression within the varietal, or heritable, limits.

The correlation between number of leaves and vegetative period naturally limits the yield per plant of forage and incidentally of grain in short-season sorghums. There are apparent varietal or heritable differences in the early development of sorghums, as some varieties joint when only a few leaves are formed while others do not joint until after the formation of additional leaves.

The number of leaves is closely associated with other characters, such as size of leaf, diameter of stalk, vigor of plant, and height of stalk. The relation of leaf number to these and other characters awaits further investigation. Some of these associations are indicated, however, by a recent graphic analysis of certain data reported by Vinall and Reed.[6]

SUMMARY

The total number of leaves on the main stalk, including those formed during the seedling stage, averaged 16 to 27 leaves per stalk, in 21 sorghum varieties.

There was a range of 5 to 10 leaves in the number on individual stalks within a variety, even when grown from selfed seed. Both season and date of planting influenced the number of leaves of a given variety.

The number of leaves and length of vegetative period were highly correlated; a correlation coefficient of 0.853 ± 0.029 having been

[6]*Loc. cit.*

obtained. The period between emergence and heading averaged 2.8 to 3.5 days per leaf for different varieties.

The number of leaves, or nodes, also is closely related to size of leaf, forage yield, diameter of stem, vigor, and height of stalk. Early maturing sorghums have few leaves and consequently are limited in production.

REACTION OF SORGHUMS TO THE ROOT, CROWN, AND SHOOT ROT OF MILO[1]

F. A. WAGNER[2]

A NEW disease that affects the roots, crown, and shoots of Dwarf Yellow milo and some other varieties of sorghum was discovered on the Garden City, Kansas, Branch Station by the writer on August 1, 1926. The symptoms of this disease apparently caused by *Pythium arrhenomanes* Drechs., and some of the control problems have been described in earlier papers (1, 2, 3, 4, 5, 6)[3].

When the disease was first noticed the infested area was very small, being confined to two spots a few feet in diameter, lying adjacent to, and apparently extending across, a cultivated alley 6 feet wide that separated two plats of Dwarf Yellow milo. The infested areas enlarged rapidly and within 12 months had completely covered the six 1/20th acre plats that made up the fertility experimental block of milo on which the disease was first discovered. The disease appeared in surrounding tracts and by 1928 a considerable area was affected. The land had been in milo each year since 1918. Beginning with the season of 1920, the land had been used for a fertility experiment with milo in which both barnyard manure and commercial fertilizer were used. One of the first two diseased spots was located in a check plat on which no fertilizer had been used and the other occurred on land that had been receiving an application of a 2-12-2 fertilizer at a rate equivalent in phosphorus to 125 pounds of superphosphate per acre annually. The two infested areas appeared to spread at the same rate. It was apparent that the previous soil treatment had little or no effect upon the disease.

The disease attacks and soon kills the plants of all varieties of milo and most hybrid derivatives of milo. Darso is also very susceptible. The first experimental work in connection with the disease produced evidence that the kafirs, feteritas, and sweet sorghums were highly resistant.

An intensive survey to determine the distribution of the disease has not been possible because of limited funds, but the disease is

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[3]Reference by number is to "Literature Cited", p. 654.

known to exist on the experiment stations at Garden City and Hays, Kan., Dalhart, Tex., and Tucumcari, N. Mex. It is also known to be present on a few farms in some of the states mentioned.

SYMPTOMS AND NATURE OF THE DISEASE

The disease is usually apparent on highly susceptible varieties within 35 to 40 days after the plants have emerged. Varieties less susceptible may appear normal in growth for a longer period, sometimes not showing any outward signs of disease for 55 to 60 days after emergence.

FIG. 1.—A, Diseased plant of Custer milo; B, healthy plant of Custer milo; C, diseased plant of Dwarf Yellow milo; and D, healthy plant of Dwarf Yellow milo. The healthy plants are average specimens grown on clean ground and the diseased plants are average plants from infested soil. Seed-bed preparation and date of planting were approximately the same in both cases.

The first indication of disease is a slight rolling or wilting of the leaves and a retarding of growth. This condition is accompanied or soon followed by an orange coloring of the outer edges of the lower leaves. The orange discoloration increases very rapidly so that within a few days (often within a day or two) it has spread over the entire area of the lower leaves (1). The plants become stunted and the more susceptible ones soon die (Fig. 1). Diseased plants gradually die but they do not show evidence of a slimy or soft rot. Occasional plants of susceptible varieties may survive until late in the season, but they are eventually killed. Diseased plants have about the same appearance as plants suffering from a deficiency of soil moisture.

Abnormal plants of milo had been observed in Kansas and other states prior to the time when the milo disease was recognized at the

Garden City Branch Station. The condition of these plants had been mistaken for injury due to chinch bugs, drought, alkali spots, soil deficiencies, and other causes and was not recognized as pathological until after its discovery at Garden City. Elliott, Wagner, and Melchers (1) and Myers (6) have shown that this abnormal condition is not due to lack of fertilizers and that it is not primarily a soil problem, although an abundant supply of nitrogen delays the development of the disease and certain other soil conditions may favor its development.

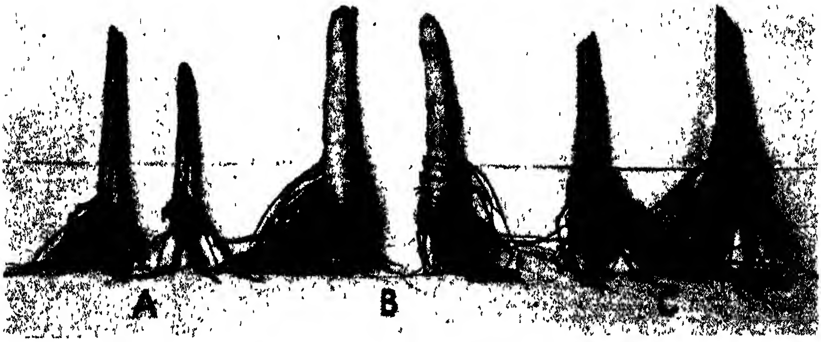

FIG. 2.—A, Longitudinal sections of the lower portion of a milo plant, including crown and roots, in an early stage of disease; B, the same view of a healthy milo plant; C, the same view of a milo plant in an advanced stage of disease.

The aboveground symptoms are accompanied by a dark red discoloration of the central cylinder of the roots and of the interior of the crown (Fig. 2). The red discoloration rapidly spreads through the crown and into the lower nodes. As the disease advances, the red turns to brown and decay may set in. There are, therefore, three symptoms that are useful in diagnosing the disease in its early stages, *viz.*, (a) wilted appearance of the plant, although it may be growing in soil containing an abundance of available moisture; (b) an orange coloring on the lower leaves, noticeable only on the margins in the earliest stages; and (c) a dark red discoloration of the central cylinder of the roots and the interior of the crown, the most reliable diagnostic symptom of the disease.

ECONOMIC IMPORTANCE

The milo disease has considerable economic importance, as milo and milo derivatives are extensively grown in the United States, particularly in Kansas, Oklahoma, and Texas. These susceptible varieties of grain sorghums cannot be grown on infested soil. Kansas produces more than 2 million bushels of milo annually and Texas much more. The potential importance of the milo disease may be better understood when it is known that Wheatland, Beaver, and other new types of grain sorghum suitable for harvesting with the combine developed in recent years for use in the wheat areas are

susceptible. Most of these new combine types are selections from kafir milo crosses and evidently carry the genetic factors for susceptibility inherited from the milo parent.

CAUSE OF THE MILO DISEASE

The cause of the milo disease has been found to be due primarily to the fungus *Pythium arrhenomanes* Drechs. (2). Intensive investigational work on this phase of the problem is being conducted by Dr. Charlotte Elliott of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and by Prof. L. E. Melchers and associates of the Department of Botany, Kansas Agricultural Experiment Station, Manhattan, Kan.

CULTURAL STUDIES AND CONTROL MEASURES

In 1928 the infested area at Garden City was planted to Dawn kafir which produced a normal crop in which there was no indication of disease. The tract was again planted to milo in 1929 but produced no grain because of damage by this disease. Two important facts had then been learned about the disease, *viz.*, (a) that Dawn kafir is highly resistant, and (b) that 1 year of cropping to kafir was not sufficient to eliminate the disease from infested soil. In 1930 several varieties of sorghums were planted on infested soil in an effort to learn if other varieties in addition to Dawn kafir were resistant.

Some rather intensive cultural and date-of-planting experiments have been conducted at Garden City since 1928 in an effort to determine methods of eradicating the disease, or controlling it to an extent that would permit milo to be grown. The following cultural experiments were started in 1929: (a) A 2-year rotation in which milo alternated with fallow, each 1 year; (b) a 3-year rotation of fallow, winter wheat, and milo, each 1 year; and (c) a 4-year rotation of fallow 1 year, winter wheat 2 years, followed by milo. These experiments have shown that milo planted on land that had been fallowed for 1 year was as badly affected by the disease as when planted on milo stubble land. Milo grown on land previously fallowed 1 year and then planted to wheat for 1 or 2 years, followed by 1 year of fallow before planting to milo, showed 100% infection. The results show conclusively that the disease cannot be controlled through the use of rotations of 4 years or less in duration.

Milo was also planted on different dates, ranging from May 15 to July 1, in an effort to find a date on which it could be planted without danger of serious infection. The disease seemed equally severe on all dates.

Elliott, at the Arlington Experiment Farm, Rosslyn, Va., and Melchers, at Manhattan, Kan., found during the course of their studies in the greenhouse in the winter of 1930–31 that susceptible varieties of sorghum would grow normally in soil from infested areas after it had been sterilized by steam or by treatment with formalin.

Soil sterilization boxes were also installed in the open field at Garden City in 1931 in cooperation with Dr. Elliott. The results obtained in the preliminary work in both greenhouse and field indicate

that the disease can be controlled through sterilization of the soil with formalin, but that the expense is too great to permit of its general use for large areas in the field.

The results obtained thus far indicate clearly that the use of resistant varieties offers the greatest hope of reducing or eliminating losses from the disease.

REACTION OF SORGHUM VARIETIES

All standard varieties of sorghum and many selections and hybrids that are known to be adapted to southwestern Kansas have been tested in the milo disease nursery at Garden City. It has been found that kafirs, feteritas, and the sweet sorghums are highly resistant to the disease and that milos and most milo derivatives are very susceptible.

The important sorghum varieties, selections, and crosses tested for their reaction to the milo disease during the 5-year period 1930–34 are listed in Table 1. A large number of pedigree selections in addition to the strains listed in the table have been studied. Those listed in the table are described as highly susceptible, resistant, immune, and segregating.

These descriptions are based on external appearances of the plants as examined in the field, and to some extent on an examination of stalks that have been split open. A more detailed classification could be made based on laboratory studies of internal symptoms, but from the standpoint of agricultural value and plant breeding interest, the simple classification used is probably sufficient. The highly susceptible class includes those strains that have shown early and severe infection. The susceptible class includes strains that are able to continue growth for a longer period before showing disease; some plants of varieties in this class appeared to be normal throughout the greater part of the season, revealing evidence of disease only when they were pulled and the roots, crown, and sections of stem carefully examined. The immune group includes varieties that have always been healthy when grown on disease-infested soil. The segregating class includes those strains that were obviously heterozygous for the genetic factors governing reaction to milo disease, i. e., in which there were both susceptible and resistant plants.

Pygmy (Two-Foot) milo (C. I. 480 × C. I. 332) 48–134, Wheatland Back-cross (C. I. 918 × C. I. 332) 1–2, Wheatland (C. I. 918), Early White milo (C. I. 480), darso, Sooner milo, and Beaver have consistently shown indications of disease somewhat earlier in the season than other varieties. Day milo, Dwarf Yellow milo, and other varieties of milo have also shown a high degree of susceptibility. Both Early White milo and Dwarf Yellow milo are highly susceptible.

Dwarf Yellow milo (C. I. 332) is one of the best grain sorghums for use in the semi-arid sections of the southern Great Plains area, and it has been largely used as one parent in crosses made by plant breeders in an effort to produce high-yielding varieties of grain sorghums with erect heads suitable for harvesting with the combine. Most crosses of these varieties that have been tested have shown early and severe infection.

TABLE 1.—*Reaction of sorghums to the root, crown, and shoot rot of milo at Garden City, Kan., 1930–34.*

Source of seed	Record No.*	Variety	Disease reaction†				
			1930	1931	1932	1933	1934
		Highly Susceptible					
Garden City, Kan.	C.I. 332	Dwarf Yellow milo	HS	HS	HS	HS	HS
Hays, Kan.	C.I. 868	Double Dwarf Yellow milo	HS	—	—	HS	—
Lawton, Okla.	T.S. 13352	Extra Dwarf White milo	—	—	—	HS	—
Lubbock, Tex.	T.S. 21195	Early Yellow milo	—	—	—	HS	HS
Hays, Kan.	C.I. 480	Early White milo	HS	HS	—	—	—
Dalhart, Tex.	C.I. 962	Early White milo ×Dwarf Yellow milo	—	—	—	HS	—
Woodward, Okla.	C.I. 959	Day milo	HS	HS	HS	—	HS
Woodward, Okla.	C.I. 917	Sooner milo	HS	HS	—	—	HS
Woodward, Okla.	C.I. 1010	Pygmy milo	—	—	HS	—	—
Woodward, Okla.	C.I. 918	Wheatland	HS	HS	HS	HS	—
Woodward, Okla.	Wdw. 1–2	Wheatland×Dwarf Yellow milo	—	HS	—	—	—
Woodward, Okla.	C.I. 960	Kafir ×Dwarf Yellow milo	—	HS	—	—	—
Woodward, Okla.	C.I. 961	Kafir×Dwarf Yellow milo	—	HS	—	HS	—
Manhattan, Kan.	Sel. 27317	Kafir×Dwarf Yellow milo	—	HS	—	—	—
Woodward, Okla.	C.I. 871	Beaver	HS	HS	HS	HS	HS
Hays, Kan.	H.C. 311‡	Dwarf Yellow milo×Pink kafir..	—	HS	HS	HS	—
Hays, Kan.	—	Custer selection	—	HS	—	—	HS
Hays, Kan.	H.C. 3310	Dwarf Yellow milo×Dwarf Freed	—	—	—	HS	—
Woodward, Okla.	—	Durra×Dwarf Yellow milo	HS	HS	—	—	—
Lawton, Okla.	C.I. 870	Desert Bishop	—	—	—	HS	—
Woodward, Okla.	C.I. 615	Darso	HS	HS	HS	—	—
Manhattan, Kan.	Sel. 30110	White darso	—	HS	HS	HS	—
Woodward, Okla.	Sel. 31–14	Sharon×darso	—	—	—	HS	HS
Lawton, Okla.	La. 32–85	Sharon×darso	—	—	—	HS	—
Dalhart, Tex.	La. 32–185	Sharon×darso	—	—	—	HS	HS
Goodwell, Okla.	A-30–1	Darso×Fargo	—	—	—	HS	—
		Susceptible					
Garden City, Kan.	G.C. 301	Day milo selection	—	S	S	S	S
Woodward, Okla.	C.I. 897	Kafir ×Dwarf Yellow milo	—	HS	Seg.	S	S
Woodward, Okla.	C.I. 898	Kafir×Dwarf Yellow milo	—	HS	Seg.	S	S
Lawton, Okla.	La. 3268	Dwarf White milo×Blackhull kafir	—	—	—	S	—
Woodward, Okla.	Wdw. 13–10	Dwarf Yellow milo ×Hegari	—	—	S	—	—
Woodward, Okla.	Wdw. 52–23	Dawn Kafir×darso	—	S	S	—	—
Hays, Kan.	H.C. 3311	Dwarf Yellow milo×Dwarf Freed	—	—	—	S	—
Manhattan, Kan.	Sel. 29247	Kansas Orange×Dwarf Yellow milo	R	S	—	—	—

		Segregating					
Hays, Kan.	C.I. 919	Custer	Seg.	Seg.	Seg.	—	—
Hays, Kan.	H.C. 313	Dwarf Kalo	—	—	Seg.	Seg.	—
Hays, Kan.	C.I. 903	Dwarf Yellow milo × kafir	Seg.	—	—	—	—
Woodward, Okla	———	Sharon kafir × Dwarf Yellow milo	—	—	—	Seg.	Seg.
Hays, Kan.	H.C. 337	Dwarf Yellow milo × Dwarf Freed	—	—	Seg.	Seg.	Seg.
		Resistant					
Garden City, Kan.	G.C.C. 11§	Dwarf Yellow milo selection	—	R	R	R	R‖
Garden City, Kan.	G.C.C. 21	Dwarf Yellow milo selection	—	Seg.	R	R	R‖
Garden City, Kan.	G.C.C. 42	Wheatland selection	—	—	R	R	R
Garden City, Kan.	G.C.C. 41	Wheatland selection	—	—	R	R	R
Garden City, Kan.	G.C. 301	Dwarf Yellow milo × Pink kafir sel. (selection from C.I. 903)	—	R	R	R	—
Woodward, Okla	C.I. 970	Kafir × Dwarf Yellow milo	R	R	R	R	—
Woodward, Okla	Wdw. 8-2-6	Kafir × Dwarf Yellow milo	—	R	R	R	—
Garden City, Kan.	G.C.C. 31	Beaver selection	—	—	S?	R	R
Garden City, Kan.	G.C. 301	Custer selection	—	R	R	R	R
Hays, Kan	H.C. 305	White Custer	—	R	R	—	—
Hays, Kan.	H.C. 338	Dwarf Yellow milo × Dwarf Freed	—	—	R	R	—
Hays, Kan.	H.C. 339	Dwarf Yellow milo × Dwarf Freed	—	—	R	R	Seg.
Hays, Kan	H.C. 336	Dwarf feterita × Dwarf Freed	—	—	—	R	—
Woodward, Okla	S.P.I. 57045**	Early White durra	—	—	—	R	—
Woodward, Okla	———	White durra (Calif.)	—	—	—	R	—
Lawton, Okla	H.C. 282	Dwarf White milo × hegari	—	—	—	R	—
Woodward, Okla.	Wdw. 14-11	Dwarf Yellow milo × hegari	—	—	R	R	R
Garden City, Kan.	G.C. 32-1	Dwarf Yellow milo × hegari (selection from Wdw. 13-10)	—	—	—	R	R
Woodward, Okla.	C.I. 809	Fargo	R	—	—	—	—
Lubbock, Tex.	F.C. 8991††	Manko	—	R	R	—	—
Woodward, Okla	C.I. 814	Bishop	—	R	—	R	—
Woodward, Okla.	Wdw. 10-1-29	Dwarf Bishop	R	R	R	R	—
Dalhart, Tex.	Wdw. 46-5	Sharon kafir × darso	—	—	—	R	—
Dalhart, Tex.	Wdw. 47-9	Sharon kafir × darso	—	—	—	R	—
Dalhart, Tex.	Wdw. 48-12	Sharon kafir × darso	—	R	R	R	R
Dalhart, Tex.	Wdw. 52-26	Dawn kafir × darso	—	—	—	R	—
Woodward, Okla	Wdw. 52-29	Dawn kafir × darso	—	—	—	R	R
Garden City, Kan	———	Sudan grass	—	—	R	—	—

TABLE 1.—*Concluded.*

Source of seed	Record No.*	Variety	Disease reaction†				
			1930	1931	1932	1933	1934
		Immune Kafirs and Kafir Relatives					
Woodward, Okla.	C.I. 628	Reed	—	I	—	—	—
Lawton, Okla.	———	Hydro	—	—	—	I	—
Lubbock, Tex.	T.S. 21193	Eason	—	—	—	I	—
Hays, Kan.	C.I. 904	Dawn selection	—	I	—	—	—
Hays, Kan.	C.I. 906	Western Blackhull	I	I	I	—	—
Dalhart, Tex.	———	Sedan	—	—	—	I	—
Manhattan, Kan	C.I. 473	Pink	I	I	—	—	—
Manhattan, Kan.	C.I. 920	Grohoma	—	I	I	—	—
Hays, Kan.	C.I. 620	Hegari	I	I	—	—	—
Garden City, Kan.	C. I. 872	Wonder	I	I	I	I	—
Hays, Kan.	C.I. 901	Club	I	I	I	I	—
Hays, Kan.	H.C. 334	Dwarf Club	—	—	—	I	—
Manhattan, Kan.	F.C. 6620	Ajax	—	I	I	—	—
Woodward, Okla.	C.I. 874	Chiltex	—	I	I	—	—
Manhattan, Kan.	C.I. 873	Premo	—	I	I	—	—
Woodward, Okla.	F.C. 8951	(Feterita × kafir) × kafir	—	I	—	—	—
Manhattan, Kan.	C.I. 182	Feterita	I	I	I	I	—
Woodward, Okla.	C.I. 623	Spur feterita	—	I	—	—	—
Lubbock, Tex.	T.S. 6312	Extra Dwarf feterita	—	—	—	I	—
Woodward, Okla.	C.I. 867	Feterita × Dwarf Shantung kaoliang No. 1	I	I	—	—	—
Woodward, Okla	C.I. 964	Dwarf feterita no. 6	I	I	—	—	—
Hays, Kan.	H.C. 312	Dwarf feterita × (milo × kafir)	—	I	I	I	—
Hays, Kan.	C.I. 902	Kalo	I	I	I	I	—
Hays, Kan.	C.I. 1009	Early Kalo	I	I	I	I	—
Hays, Kan.	C.I. 971	Dwarf Freed	I	I	I	I	—
Manhattan, Kan.	C.I. 905	Modoc	—	I	I	—	—
Tribune, Kan.	C.I. 972	Greeley	—	I	—	—	—
Tribune, Kan.	C.I. 973	Pink Freed no. 14	—	I	—	—	—
Tribune, Kan.	C.I. 974	Pink Freed no. 36	—	I	—	—	—

		Immune Sorgos					
Manhattan, Kan.	F.C. 7038	Red Amber	—	I	—	—	—
Manhattan, Kan.	F.C. 6610	Leoti Red	I	I	—	—	—
Garden City, Kan.	———	G. C. "Honey" (Sapling)	—	—	I	I	—
Chillicothe, Tex.	F.C. 16185	Red X	—	—	—	I	I
Manhattan, Kan.	F.C. 6611	Early Sumac	I	I	—	—	—
Garden City, Kan.	C.I. 472	Sunrise	I	I	—	—	—
Manhattan, Kan.	Hays 30–14	Atlas × Early Sumac	—	I	I	—	—
Hays, Kan.	F.C. 16187	Sumac × White African	—	—	I	—	—
Manhattan, Kan.	Sel. 2473	Red Amber × feterita	—	I	I	—	—

*C.I. refers to accession number of the Division of Cereal Crops and Diseases formerly Office of Cereal Investigation. T.S. refers to Texas Station number.
†HS = Highly susceptible; S = Susceptible; Seg = Segregating; R = Resistant; I = Immune.
‡H.C. refers to Fort Hays Branch Experiment Station Cereal number.
||All plants appeared to be normal when observed in the field, although approximately 4 to 6% of the plants showed a slight infection in the crown when examined in longitudinal section.
§G.C.C. refers to Garden City Branch Experiment Station Cereal number.
**S.P.I. refers to accession number of Division of Plant Exploration and Introduction.
††F.C. refers to accession number of Division of Forage Crops and Diseases.

A few milo crosses, however, have proved to be highly resistant. Among them are some rather promising new varieties and strains such as Kalo, Early Kalo, Dwarf feterita × (milo × kafir) (H. C. 312); milo × hegari, Woodward selections Nos. 13–10, 14–11, and Hays selection H. C. 282, kafir × milo, Woodward selections Nos. 38–1–2–1, 10–1–29, and 8–2–6; and Dwarf Yellow milo × Dwarf Freed, Hays selection 339. Fargo (C. I. 809) and Manko Maize are the only two varieties resembling Dwarf Yellow milo in seed and certain plant characters that in their original form have shown natural immunity from the milo disease.

Feterita (C. I. 182), Spur feterita (C. I. 623), and three Dwarf feteritas were included in the tests and were found to be resistant to the milo disease. Dwarf Freed (C. I. 971), Grohoma, hegari, and Sudan grass also have shown no indication of the disease.

About 12 strains of kafir and 8 varieties of sorgos, or sweet sorghums, were grown on infested soil and found resistant. Darso, a grain sorghum having juicy, sweet stalks, and brown, bitter seed, has shown unusual susceptibility to the disease.

The few hybrids between resistant varieties that were included in the experiments were found resistant to the disease.

Rex (Red X) sorgo, a forage variety that had shown both normal and abnormal plants at Chillicothe, Tex., was included in the experiment at Garden City in 1933. Seed of the normal and abnormal types was planted in separate rows. The strain that had produced normal plants at Chillicothe also appeared healthy in the Garden City tests, while the strain that had produced abnormal plants at Chillicothe produced very low growing, subnormal plants at Garden City. These plants did not show typical indications of milo disease. When the plants were pulled and examined at the close of the growing season, there was no apparent root or crown injury. The abnormal condition of the plants was evidently brought about by some factor other than the milo disease organism.

Under normal conditions, Dwarf Yellow milo is one of the highest yielding varieties of grain sorghum for southwestern Kansas and adjacent territory. Most of the new types that have been developed from milo × kafir crosses for harvesting with the wheat combine harvester-thresher carry factors for susceptibility to milo disease. It is highly desirable, therefore, that a resistant milo be developed. The first step in that direction was made in the fall of 1930, when two plants of Dwarf Yellow milo apparently normal in every way were found growing on an infested plat of ground where all other milo plants had died. All heads were saved from the two healthy plants. One head was selected from each plant for planting in headrows in 1931. One headrow produced plants free of disease and the other produced both healthy and diseased plants. In this way, a disease-resistant strain of Dwarf Yellow milo has been produced which is very similar to the variety from which it was selected, except for resistance to the milo disease (Fig. 3).

During the season of 1933 this resistant selection of Dwarf Yellow milo was compared with ordinary Dwarf Yellow milo on disease-free soil (5). The data secured indicate that it is capable of yielding fully

as well on uninfested ground as the ordinary Dwarf Yellow milo. Further tests were made in 1934 and 1935. If results continue to be favorable, the disease-resistant selection will be given a varietal name or pedigree number and seed will be increased for distribution to farmers in southwestern Kansas.

FIG. 3.—Ordinary Dwarf Yellow milo in two center rows vs. Garden City Disease Resistant Dwarf Yellow milo on either side.

Considerable time has been given to a study of Beaver, Wheatland, and Day milo, as grown on infested soil, in an effort to develop resistant strains of these varieties. A strain of Beaver has been selected that is very similar to ordinary Beaver except that it is resistant to the milo disease. Several lines of resistant Wheatland have also been selected. These resistant selections are now being tested for yield, resistance to lodging, and other agronomic characters (Fig. 4). Progress is also being made toward the production of a disease-resistant strain of Day milo.

A duplicate planting of the milo disease nursery as grown at Garden City was made on the U. S. Dry Land Field Station at Dalhart, Tex., in 1932, in cooperation with B. F. Barnes. The reaction of all varieties, selections, and hybrids in the plantings at Dalhart was very similar to that at Garden City, indicating that the milo disease in the Dalhart territory is closely related to, and probably identical with, the disease in the Garden City district.

SUMMARY AND CONCLUSIONS

A disease known as the root, crown, and shoot rot of milo is described and reported as occurring in Kansas, Texas, New Mexico, and possibly California and Oklahoma.

The disease cannot be controlled by any of the ordinary methods of cultivation or rotation or by changing the time of planting the crop.

Studies on varietal susceptibility in the milo disease nursery at Garden City, Kan., have proved that milo and most milo derivatives are very susceptible. Darso is also highly susceptible. Kafirs, fe-

teritas, and most sorgos are highly resistant to the disease. The sorghum varieties, selections, and crosses tested on infested soil at Garden City are listed and described as highly susceptible, resistant, immune, or segregating, as the case may be.

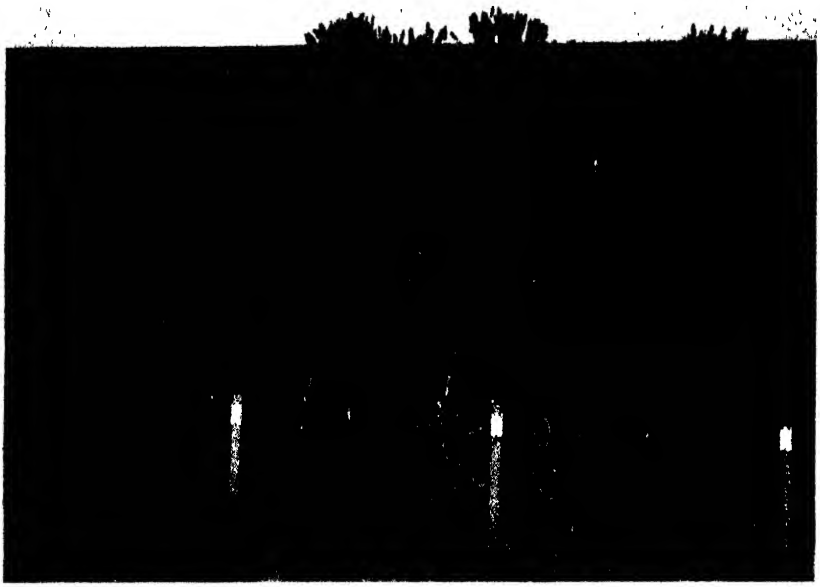

FIG. 4.—A resistant selection of Wheatland (A), ordinary Wheatland (B), and ordinary Dwarf Yellow milo (C) grown on infested soil.

The disease can be controlled by the use of resistant varieties or resistant strains of susceptible varieties. Resistant strains of Dwarf Yellow milo, Wheatland, and Beaver have been selected and seed may be available in the near future for distribution to farmers.

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METHODS FOR INSPECTION OF COMMERCIAL LEGUME INOCULANTS[1]

Alvin W. Hofer[2]

METHODS for inspection of legume inoculants have varied greatly with progress in the knowledge of the root nodule bacteria. Recent interest in standardization of procedures suggests the need for a review of the more important facts relative to their development. Furthermore, additional information which indicates that bacterial strains vary in their ability to help the host makes necessary a reconsideration of the whole technic. This review is a survey of the more important papers concerning methods for legume inoculant inspection.

Because the division seems logical, the time since Nitragin was first sold and the present is divided into two periods. The first is characterized by the solution of many of the fundamental problems necessary for the manufacture of legume inoculants and by the beginning of legume inoculant inspection (Galloway, 14)[3]. It is therefore called the period of fundamental development (1895 to 1917). The second period includes (a) the time of general acceptance of the idea of inoculation with artificial cultures, (b) the growth of the industry, and (c) the development of the practice of routine inspection. This period can best be designated as that of practical development (1918 to date). The year 1918 is taken as a logical point of departure from the early attempts to manufacture artificial cultures because of an increased interest in inspection and especially in methods (Fellers, 34, and Noyes and Cromer, 37). In fact, the investigations in the early part of the second period really represented a discovery of the need for routine inspection by state governments. A few years later, legislatures began to provide for inspection upon a routine basis.

GREENHOUSE METHODS

At the present time the greenhouse technic is the most important part of the inspection procedure. Only recently, however, have methods of growing legumes in pots improved to such a point that contamination with extraneous legume bacteria is no longer a serious factor. In spite of sterilization of sand, seeds, and water, the first tests were often confused by contaminations (Dawson, 9, Stevens and Temple, 18, Feilitzen and Nyström, 30, and Temple, 33).

[1]Contribution from the Division of Bacteriology, New York State Agricultural Experiment Station, Geneva, N. Y. Approved by the Director for publication as Journal Paper No. 145, June 9, 1936. This paper was suggested by discussions at two round table conferences, presided over by the author, of those interested in the testing of legume inoculants at the last two annual meetings of the Society. It is hoped that it will form a basis for further discussion and possibly for definite recommendations at the forthcoming conference of this same group in Washington in November of this year. Received for publication June 10, 1936.

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[3]Figures in parentheses refer to "Literature Cited", p. 665.

At that time sand was sometimes sterilized for 2 hours at 150°C in in a covered kettle over an open fire and the cooled sand then placed in pots previously sterilized with mercuric chloride (Hellriegel, 2). Another method consisted of placing the sandy soil in a tight box with a perforated pipe through which steam was passed for an hour a day on three successive days (Munson, 6). Fertilization and then sterilization for 4 to 5 hours at 120° to 130°C resulted in some plant injury, especially in the uninoculated series (Maercker and Steffeck, 5). Dawson (9) heated soil for 24 hours at 200°, Grandeau (21) and Feilitzen (20) for a half hour at 125° to 130° C, and Stevens and Temple (18) for 1 hour at 120°C.

SEED STERILIZATION

In the beginning, seeds were frequently sterilized with mercuric chloride (Hellriegel, 2, Dawson, 9, and Grandeau, 21). Robinson (24), however, found that even after seeds treated with this reagent had been washed four times, the wash water still contained enough of the disinfectant to be toxic to the bacteria. With seed coats that were difficult to penetrate, and which required a longer period of sterilization, the time required for removal of the disinfectant was longer. Chemical sterilization under reduced pressures was more efficient, but again, the disinfectant was harder to remove.

The difficulty of complete sterilization with any agent, was demonstrated by de Zeeuw (26), who found molds frequent in some lots of seed. Garman and Didlake (31) also found molds frequent in their method for growing plants on agar, regardless of the disinfectant used. Perhaps the need for a strong disinfectant explains the continued use of mercuric chloride. Fellers (34, 39) used it because he felt that it could be depended upon for sterilization, and because additional seeds could always be planted to make up for any that were killed. Apparently, the advantages of seed sterilization were sufficient to outweigh the dangers from toxic residues apparent as small traces of mercuric chloride in the filtrate from washed, crushed beans.

The problem was investigated further by Haas and Fred (40) and by Anderson and Walker (83). These investigators agreed that seeds treated with mercuric chloride were capable of inhibiting bacterial growth even after careful washing, as shown by sterile zones around seeds on petri plates inoculated with homologous strains of legume bacteria. While the latter authors usually found a distinct loss in germination, they believed the problem to be more serious in the case of larger seeds.

Anderson and Walker (83) preferred to use hydrogen peroxide because of the lack of harmful residues and because it stimulated germination. Robinson (24) also found hydrogen peroxide effective and easily removed from the seed; but Fellers (39) failed to secure complete sterilization by its use, although he did notice a stimulating effect upon germination. Noyes and Cromer (37), on the other hand, secured complete sterilization, with almost perfect germination, while Walker and Erdman (60) stated that this reagent used in 10 to 15% concentration for 30 minutes at room temperature gave

excellent results. Washing of seeds was said to be unnecessary. Large legume seeds were again found to be very easy to sterilize in experiments by Kisser and Portheim (126). Any lack of effectiveness could apparently be improved by addition of traces of ferric cuprous sulfates, or potassium chromate with manganous or cobaltous sulfate (Dittmar, Baldwin, and Miller, 78). These authors found that in the case of *Escherichia coli* the germicidal efficiency was raised from a phenol coefficient of 0.014 to one of 1.4 by this method, while corresponding results were obtained with *Staphylococcus aureus*. This discovery may have some connection with the statement of Curran (156) that the effectiveness of hydrogen peroxide is closely correlated with the presence or absence of active catalase or peroxidase.

Chlorine used in the form of chlorinated lime (Wilson, 32) is another agent which has proved its efficiency for sterilizing seeds. Fellers (39) found that the use of this agent provided effective sterilization without seed injury. The same results were obtained by Duggar and Davis (38), but they preferred the chlorine in the form of Javelle water. The latter authors found no injury to germination, with practically complete sterilization and removal of all toxic substances. The difficulties of the process were minimized by previous removal of injured or decaying seeds, while in certain cases intermittent sterilization was thought to have value, due possibly to the killing of those organisms which Robinson (24) suggested as occuring under the seedcoat.

Other disinfectants which have been used are (a) formalin (Stevens and Temple, 18, Garman and Didlake, 31, Fellers, 39, and Duggar and Davis, 38), and (b) alcohol (Feilitzen, 25, Feilitzen and Nyström, 30, and Duggar and Davis, 38). Formalin had a severely detrimental effect upon germination of seeds and was incapable of bringing about complete sterilization. In fact, the difficulties with contamination experienced by Stevens and Temple (18) might conceivably be traced to the use of formalin. Alcohol did not injure the seeds, but failed to sterilize them.

A questionnaire on methods of sterilization shows that a number of sterilizing agents are in common use, as follows:

I. H. Curie, Baltic, Ohio.—Place seed in 10% hydrogen peroxide for 10 minutes with frequent stirring. Pour off liquid and rinse five times with sterile water. Place in sterile blotting paper boxes covered with sterile blotting paper, and allow to remain at room temperature. Plant within 48 hours.

R. H. Thexton, Ottawa, Canada.—Soak seed in 1:500 mercuric chloride for 15 minutes with frequent stirring. Wash in sterile tap water four times.

W. B. Sarles, Madison, Wis.—Treatment for alfalfa, sweet clover, true clovers, lespedeza, peas and vetch consists of the following: Place in 95% alcohol for 5 minutes, wash in sterile distilled water, immerse in calcium hypochlorite solution, after 60 minutes, wash 6 times in sterile distilled water, and dry in a shallow layer at 37°C for 3 hours. Treatment for soybeans, beans, lima beans, and similar seeds is carried out by soaking in distilled water for 5 minutes, placing in calcium hypochlorite solution for 10 minutes (seeds must be free of air bubbles), wash 6 times in sterile distilled water, and plant immediately. Prepare calcium hypochlorite solution by mixing 10 grams of fresh chlorinated lime with 140 cc of distilled water. Filter through filter paper and use at once.

J. K. Wilson, Ithaca, N. Y.—Immerse hard-coated seeds in concentrated H_2SO_4 and remove as experience shows that they have been exposed long enough. After washing in cold water to remove acid, these seeds and all others that do not get the acid treatment are treated with a solution of calcium hypochlorite (fresh 10 grams to 140 of water and filter). Watch the time period closely; usually 15 to 20 minutes is sufficient. Wash in distilled or sterile water, drain, and plant while seeds are still smelling of chlorine.

N. Porges, New Brunswick, N. J.—Select seeds which, by greenhouse tests, are practically free of legume bacteria. If necessary, seeds may be immersed in water at 65°C for 4 to 5 minutes.

L. T. Leonard, Washington, D. C.—Agitate seeds in 1:500 mercuric chloride for 15 minutes. Pour off and rinse 4 times with sterile water. After removal of last wash water, drain excess water into the cotton plug, and replace with a dry plug, if necessary.

A. W. Hofer, Geneva, N. Y.—Place seeds in hypochlorite solution, as above, sterilize with occasional shaking, rinse 6 times with sterile distilled water, and place at 37°C to dry. Drying must be fairly complete if lots of seed are to be weighed before inoculation.

R. H. Walker, Ames, Iowa.—Place seeds in 10 to 15% hydrogen peroxide for 30 minutes at room temperature

The group interested in uniformity of processes has as its first object the standardization of methods for seed sterilization, so that in another year or two the present complicated situation may be somewhat clearer.

SUBSTRATES FOR PLANT GROWTH

In the inspection procedures, many types of soil and sand have been used. These have ranged from sterile silica sand and sterile forest soil (Dickson and Malpeaux, 3) to loam rich in humus (Maercker and Steffeck, 5). In general, nitrogen-deficient soils were used, and as these were often lacking in other necessary elements fertilization of various degrees was practiced. The elements most frequently added were calcium, phosphorus, and potassium (Remy, 16, Feilitzen, 25). Sulfur was sometimes added, especially as a carrier of magnesium, (Dickson and Malpeaux, 3, Maercker and Steffeck, 5, Harrison and Barlow, 17, Grandeau, 21, Stevens and Temple, 18, and Lipman, 23). In one case at least, traces of iron were added (Lipman, 23). The importance of the various elements is discussed by Fred, Baldwin, and McCoy (100).

Of the added elements, calcium is perhaps most valuable. It is important in relation to acidity, plant growth, phosphorus availability, soil structure, soil formation, alkali soils, base-exchange capacity, and use of fertilizers (Kelley, 138). In general, the most favorable pH range is from 4.5 to 8.0 and varies with the plant, the optimum being about pH 6.5 (Fred, Baldwin, and McCoy, 100). In soils more acid than pH 5.0, lack of nodule formation on soybeans was due to acidity (Albrecht, 106). Slightly above that point, addition of calcium in amounts not sufficient to change the pH brought about nodule formation, thus showing its value as an element rather than as a base.

In consideration of the beneficial effects obtained with phosphorus in most field soils, this element might well be added to calcium in any nutrient solution for plants. The deficiency of some soils in potassium should also lead to the frequent use of this element. None of these, however, should be added in large amounts as soluble salts (Helz and Whiting, 71). Even without an extensive survey of the literature and without conclusive data for magnesium and sulfur (Fred, Baldwin, and McCoy, 100), it can be stated that certain other elements can often be used advantageously. Boron and manganese seem to be absolutely essential for the growth of plants (Brenchley and Thornton, 51 and Hopkins, 125). In certain cases zinc appears necessary (Reed and Dufrénoy, 143). Of course, some of these rarer elements can be added in fertilizers (Young, 155), but if this is done there is still danger of using too great quantities.

The use of nitrogen, however, is a different type of problem from the above. Most investigators omit all forms of nitrogen, (Giöbel, 58, and Baldwin, Fred and McCoy, 100), but recent reports suggest that small amounts may be beneficial. Burgevin, (110) and Roux (145) report that a small application of mineral nitrogen is valuable for stimulation of the initial growth. Orcutt and Wilson (142) found that intermediate concentrations of nitrate apparently stimulated photosynthesis and nodulation. Addition of small quantities of nitrate increased the amount of soluble sugar in the sap, the size of the plant, and the rate of nitrogen fixation. In the light of the numerous unfavorable reports, the use of nitrate in routine tests would be of uncertain value at the present time. While there may be advantages in use of the proper concentrations, the dangers are such that this practice cannot be considered for routine inspection without a great deal of further study.

A closely related factor is the effect of light and carbon dioxide. These seem to be definitely associated with the fixation and use of nitrogen by the plants. Sucrose in the medium makes possible the development of nodules on plants grown in complete absence of light (Wilson, 92). Nodules have even been grown on excised roots of beans by addition of sugar (Lewis and McCoy, 116). Nitrogen fixation by legumes is said to be limited frequently by the carbohydrate synthesis of the plant, due to low carbon dioxide content of the air (Fred and Wilson, 123). The depressing effect of nitrate on the carbohydrate supply is the reason for the poor nodulation usually obtained when nitrate is used. Allison (131) found both nodule formation and nitrogen fixation to be dependent upon the carbohydrate supply. In actual practice this can be improved by increasing photosynthesis, which in turn, is speeded by increased light (Wilson and Georgi, 105) or a higher pressure of CO_2 in the air (Wilson, Fred, and Salmon, 118, and Georgi, Orcutt and Wilson, 112).

On the other hand, there is evidence to indicate that the supply of carbohydrates may be too large. Hopkins (137) found that in certain experiments, shading of plants was apparently beneficial, while Orcutt and Fred (141) report an experience where a high light intensity of plants grown outdoors prevented nitrogen fixation, even though nodules were present. After shading for 1 week, the plants doubled

in size. This raises the question of what light intensity can be considered optimum for routine tests.

Moisture is another important factor in the growth of legume plants. As early as 1893, Gain (1) reported that nodule formation occurs most readily in a fairly moist soil. This was verified by others (Fred, Baldwin, and McCoy, 100). Virtanen and Hausen (151) found that a free access of air to the roots resulted in increased nitrogen fixation. Wilson (91) discovered that reduced moisture for beans was followed by shedding of nodules, while an increased supply allowed redevelopment of nodules. Livingston (36) and Deatrick (64) added water by means of auto-irrigator cones. The latter prevented saturation of the soil by means of resistance exerted by a heavy column of water. Hofer (135) controlled moisture in sterilized pots for growth of legume plants by use of a simple apparatus consisting of auto-irrigator cones with a column of mercury to regulate the flow of water in each inlet tube.

DETERMINATION OF QUALITY

Evaluation of cultures is complicated by the recent discovery that there is variation among the different strains of *Rhizobium*. Thus, these organisms are not fundamentally different from other living things in this important respect. The phase of variation which is of most interest, however, is that concerned with the great differences in nitrogen fixation shown by certain strains (Stevens, 54, Wright, 55, Helz, Baldwin and Fred, 67, Vandecaveye, 104, Virtanen and Hausen, 152, and Thornton, 149).

The most effective strains are those that develop nodules near the top of the root system, while the non-effective strains are those that develop small nodules scattered through the root system. The characteristics of a strain are not permanent, however, as the nitrogen-fixing abilities are changed by passage through plants (Allen and Baldwin, 82). The situation is further complicated by the fact that strains from one plant may not be well adapted to other plants, even in the same cross-inoculation group; in fact there is one instance (Leonard and Dodson, 115) where low yields of Austrian winter peas were found to be due to the presence in nodules of bacteria from Louisiana vetch (*Vicia ludoviciana*).

The extent of the variation among strains is shown by the work of Virtanen and Hausen (152) who found that some fix three times as much nitrogen as others. Winter killing of clover was found to be most severe with the weaker strains. These experiments emphasize the belief of Erdman (56) that number and size of nodules should be considered in any evaluation of cultures. Nevertheless, in the light of the above findings, it appears that even this is not enough. Tests will not provide the information of greatest importance until they measure the effect of the organism upon its host. Methods for accomplishment of this result, however, in view especially of the work with light (Hopkins, 137 and Orcutt and Fred, 141), will require a great deal of further investigation.

FIELD METHODS

Early field tests were complicated by the fact that the cultures were sometimes mixed with soil before application. In some cases the field was inoculated rather than the seed. Nevertheless, even before 1900, inoculation was sufficiently successful to arouse great interest. Many of the early studies in America were stimulated by the work of Duggar (4) who reported inoculation increases of 1,000%. The various soils, both in this country and abroad, were fertilized much in accordance with their particular needs.

In general, field tests were very time-consuming and uncertain (Makrinoff, 48). The tests proved of less value under any of the following conditions: (a) If the organisms were already present in the soil (Frank, 7, and Gerlach and Vogel, 19), (b) if the weather was unfavorable (Keeble and Cayley, 22), (c) if the plants suffered from excessive soil acidity or alkalinity (Wollny, 8), or (d) if animals or insects affect the crop (Feilitzen, 25). Griem (private communication, 1936) says further that there is difficulty in planting all the types of seed at the optimum planting time and that there are many variables, including moisture conditions, temperature relations, and soil nitrate concentrations. Good agronomic practice would suggest, also, that a number of replicates be carried for each culture if a reliable average is to be obtained. As a result of these factors, it is apparent that practical difficulties prevent wide use of field tests in spite of their many advantages. The field tests of Batchelor, *et al.* (84) and of Albrecht (76) are among the few recent ones which gave a sufficient degree of satisfaction to make a report possible.

LABORATORY METHODS

Laboratory inspection of legume inoculants as compared to greenhouse and field methods is not particularly complicated, but it is not definitely related to farm practice. Laboratory tests have been used since early days, however, in connection with the other methods. Maercker and Steffeck (5) not only evaluated cultures by microscopic examination, but confirmed their conclusions by greenhouse tests. Bredemann (27) observed numerous spores by microscopic examination; when the culture was heated and plated, colonies of sporeformers were obtained. Harding and Prucha (13) used laboratory tests very effectively for a study of cotton cultures. Remy (16), on the contrary, found plate counts unsuitable for this work, because of the presence of contaminating organisms.

Wilson and Kullmann (94), in a study of the plate count, found that usually one plate in a series varied greatly. When this was discarded, the results were fairly satisfactory. Nevertheless, they favored the use of a counting chamber (Petroff-Hauser). The value of the plate count on old cultures is also impaired by the fact that only a varying small proportion of the bacteria are able to form nodules (Reid, Fred, and Baldwin, 144).

In the past, further difficulty occurred because of lack of methods for recognizing the presence of organisms similar to the legume bacteria. *Bacterium radiobacter* (Beijerinck and van Delden, (11) was

first distinguished from *Rhizobium* by the use of litmus milk and potato slants (Löhnis and Hansen, 41). Since these media produce rather variable results, a number of others have recently been proposed for the purpose (Smith, 73, Hofer and Baldwin, 102, Hofer, 114, 136, and Sarles, McCaffrey and Mickelson, 146). Media of high alkalinity distinguish between the organisms nicely. Litmus milk and veal infusion are suitable for purity tests. Methods for detection of contaminating organisms, and especially *Bacterium radiobacter*, are important in view of the fact that this organism is frequently found in commercial cultures (Leonard, 88).

Another difficulty with the plate count lies in the fact that there is no method for distinguishing between the bacteria of the various cross-inoculation groups on laboratory media. In fact, the work of Wilson (159) would indicate that this may never be possible because of cross-inoculation within wider limits than had previously been suspected. Also, non-infective, atypical bacteria (Almon and Baldwin, 107, Baldwin and Hofer, 97) may sometimes produce colonies on plates without indication that they are abnormal. In spite of these defects, plate counts are of value for determination of the faults of manufacture which have resulted in the production of inferior cultures (Hofer, unpublished data). Atypical colonies on plates occasionally betray the reason for lack of nodule formation in the greenhouse, while low numbers of bacteria or numerous dead bacteria, as shown by high turbidity in dilution blanks and low plate counts, make themselves known and serve as clues to the difficulties involved.

In fact, if it were not for the advantages of the plate count and for the space and material required for greenhouse counts (Leonard, 81), it is likely that the dilution method of Wilson (62) would have come into wider use. As it is, this method possesses advantages which commend it for certain phases of legume inoculant inspection, especially in regard to determination of numbers of *Rhizobium sp.* in impure materials, such as peat. Nevertheless, as commercial companies solve the fundamental difficulties involved and produce cultures which contain sufficient numbers of nodule-forming bacteria, the need for counts will decrease. For this reason, investigations of methods for counting are perhaps not as important as other phases of inspection.

So long as plate counts are used, however, there are two fundamental problems the first of which is in regard to a proper dilution fluid. Although sterile tap water has been used by Fellers (34) and by Hofer and Conn (87), distilled water is more constant in composition. It is frequently toxic, however (Wilson, *et al.* 154). Mudge and Lawler (72) state, on the contrary, that clumps of bacteria are dispersed in a milk-distilled water dilution blank with consequent increases in counts. Butterfield (98) reports the use of a phosphate solution in water analysis, without either rapid death or increase of the bacteria. In the *Standard Methods of Water Analysis* (158), it is stated that, "The water used for dilution shall be tap water, or the phosphate dilution water recommended in the procedure for Biochemical oxygen demand (Part III, Sec. XII). Distilled water shall not be used."

The other question is in regard to culture media. Standard beef agar (Stevens and Temple, 18), plant extracts (Hiltner, 12, Allison, 63), soil extract (Leonard, 1936, private communication) and yeast-water, mannitol media (Fred and Waksman, 69) have been used for the purpose. Late discoveries indicate possibilities for development of synthetic media for the purpose. Sarles and Reid (147) have found asparagin to exert some of the favorable effects of potato extract. Yeast extract is used at present as a nitrogen source which is very favorable to the growth of *Rhizobium* (Walker, Anderson, and Brown, 129). An accessory factor for growth of legume bacteria has been found on samples of cane sugar (Allison and Hoover, 119, and Thorne and Walker, 148). Arabinose has been stated to be distinctly superior to some other carbon sources for growth of soybean bacteria (Neal and Walker, 140). Further possibilities arise in connection with maintenance of pH at a constant level, somewhat as suggested by plant investigations (Trelease and Trelease 150). Achievement of uniform oxidation-reduction potentials is also desirable, if not essential (Allyn and Baldwin, 77, 96).

PRESENT INSPECTION METHODS

Laboratories which at the present time conduct routine tests of legume inoculants are located in New Jersey, Wisconsin, New York, and the U. S. Dept. of Agriculture. Greenhouse tests are a part of the procedure in every case. Usually, seed is inoculated in the proportions recommended by the manufacturer and plants are grown in sterilized sand. Sterile water is added as needed with frequent addition of nutrient solutions, Crone's solution (Bryan, 42). Sand is sterilized by prolonged heating in an autoclave, while water or nutrient solutions are frequently sterilized by 15 pounds steam pressure for an hour.

The value of the culture is judged by the presence or absence of nodules on the host plant. Of late years some investigators (Hofer, unpublished data) also use a second dilution composed of 1/10 the number of bacteria recommended by the manufacturer (Nobbe and Hiltner, 10). The weaker dilution gives an indication of weaknesses which would not be evident if the manufacturer's dilution alone were used. Some laboratories use plate counts for the same reason and to arrive at a close approximation of the worth of individual cultures. These are generally used only on pure cultures, because the humus type frequently contains numerous other bacteria, such as actinomyees or molds (Hofer, 157). Field tests are attempted occasionally, but there is no other common method for determining the effect of the culture upon its host. In general, the tests are designed to show whether inoculants are successful in bringing about nodulation on the hosts for which they are intended when used in the proportions recommended by the manufacturer.

POSSIBILITIES FOR THE FUTURE

As was evident in the case of seed sterilization, methods for inspection vary from laboratory to laboratory. For this reason, an attempt is under way to bring about greater standardization and the following outline is presented as a guide for further study.

OUTLINE OF PROBLEMS IN ROUTINE INOCULANT INSPECTION

I. The sample
1. Method of removal.
2. Type of dilution container.
3. Composition of dilution fluid.
4. Best method for shaking dilutions.
5. Removal of aliquot.

II. Laboratory tests
1. Choice of a medium.
2. Time for incubation of plates.
3. Media for purity tests.
4. Possibilities for new laboratory tests.

III. Preparation of seed
1. Size of seed portions.
2. Method of seed sterilization.
3. Amount of water to use on seed.

IV. Greenhouse routine
1. Type of container.
2. Number of pots or jars per sample.
3. Number of host plants.
4. Two hosts in one pot, i.e., alfalfa and sweet clover?
5. Time period for plant growth.
6. Nutrient solutions.
7. Greenhouse humidity.
8. Proper amount of moisture in soil.
9. Proper temperature, or temperature range.
10. Co_2 pressure.
11. General setup.
12. Control of contamination.
13. Time of year for tests.
14. Detection of disease.
15. Adverse effects of bacteriophage (Demolon and Dunez, 121).

V. Results
1. Evaluation.
   (a) Place of the plate count.
   (b) Place of supplementary greenhouse methods.
   (c) Use of common greenhouse methods, and determination of what they reveal. Number and distribution of nodules.
2. Publication of results—arrangement of data.

VI. Field tests
1. Their place in the general plan.
2. Layout of plots.
3. Rules.

VII. Other tests of efficiency
1. Their place in the general plan.
2. Equipment for tests on efficiency.

The greatest single development, however, that can reasonably be expected in the future, and one which is badly needed, is a simple test of the nitrogen-fixing ability of the different cultures. This is obviously the question in which the purchaser is ultimately interested, but the actual development of such a test is beset by many difficulties, as shown by the above report. Possibly the best approach may be through attempts to correlate the greenhouse methods with field results to learn the proper conditions, especially of light, temperature, and moisture. The difficulty of this is increased by the fact that in the field these factors are not constant. Also, variation of these relationships may be required for best plant growth so that it may be necessary not only to discover the optima, but also the maxima and minima.

CONCLUSIONS

A review of new methods for legume inoculant inspection suggests several possibilities for improvement. The most important consists of a change from the present plan of examination for nodules to one that will measure the benefit which the individual cultures confer upon their hosts. At the present time the tests do not accomplish all that they might; they are still in a period of development.

Improvement of inspection by use of a simple greenhouse efficiency test that correlates fairly well with field results is much to be desired. The actual realization of a workable plan for bringing the tests into close harmony with fundamental science and practical agriculture would have real value. It would, in fact, represent the end of the period of development in legume inoculant inspection and the beginning of a new period of practical utility based upon modern scientific knowledge.

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REACTION OF WHEAT VARIETIES TO COMPOSITES OF RACES OF BUNT OCCURRING IN THE PACIFIC NORTHWEST[1]

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TSCHARNER, according to Woolman and Humphrey (16)[3], was the first to mention a varietal difference for resistance of wheat to bunt when he stated in 1764 that white spelt was more liable to bunt than red spelt. Since that time, considerable data have been published showing that varieties differ in their resistance to the bunt organism. In 1924, Faris (7) published the first evidence of physiologic specialization in bunt.

About a decade ago, the quest for high-yielding varieties of wheat which also were resistant to bunt (*Tilletia tritici* (Bjerk.) Wint., and *T. levis* Kühn) appeared relatively simple. In 1922, Stephens and Woolman (13) found in their experiments nearly 20 varieties thought to be safe for sowing without seed treatment, but many of them were not suitable for commercial production. Schafer, Gaines, and Barbee (11) reported in 1926 that Albit, Hussar, Martin, Ridit, and White Odessa were 100% resistant in their trials.

In recent years, physiologic races have been found which infect most of the varieties formerly considered highly resistant or immune. Luckily, there are differential reactions between resistant wheat varieties and the more virulent races of bunt, and a number of varieties are resistant to many races. While the development by hybridization of agronomically desirable smut-resistant wheats is more involved than it formerly appeared to be, it nevertheless remains feasible. Some of the most virulent races of bunt known to exist have been found within relatively small areas in the Columbia Basin of Oregon, Washington, and Idaho. The investigations reported herein were made to determine the relative susceptibility and resistance of most of the wheat varieties grown in the United States to collections of bunt from the dry lands of the Pacific Northwest. Tests of this kind should provide valuable information for use in hybridization programs.

MATERIAL AND METHODS

A total of 250 varieties, including common, club, durum, emmer, poulard, Polish, and wheat × rye, were tested in 1934 at Pendleton, Ore., for resistance to two composites of bunt collections. The inoculum for one series was composed of collections obtained within a 10-mile radius of the Pendleton Field Station, while that for the second series was a composite of collections from several localities in the dry land sections of the Pacific Northwest. The Northwest composite contained both *Tilletia tritici* and *T. levis*, but the local composite was largely *T. tritici* with only a trace of *T. levis*. No attempt was made to composite

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[3]Reference by number is to "Literature Cited", p. 681.

pure physiologic races, but from reactions of the host varieties it may be assumed that there were several races present. There are obvious disadvantages in using composite cultures instead of pure races. Results from composites seem sufficiently accurate for practical purposes, however, and the data are applicable to a wide range when the inoculum has been secured from several localities.

All varieties in the trial were inoculated in the fall of 1933 with bunt spores by shaking the seed and spores together in coin envelopes and then were sown in single 16-foot rows. Although Aamodt (1) has shown that replication is desirable in trials of this kind, the climatic and soil conditions at Pendleton are such that variations due to chance escape are of little importance. All varieties were highly infected unless they possessed considerable resistance to the disease.

The percentages of infection were determined from head counts. Most of the rows contained 500 or more heads. Some difficulty was experienced in detecting bunted heads in varieties with brown or black glumes. Diseased heads were easily recognized, however, when allowed to stand after maturity long enough for some of the coloring to be bleached from the glumes. In many cases, particularly in heavily infected varieties, bunted plants could be detected at least 2 weeks before the emergence of any heads. These plants were shorter and had more profuse foliage, while the leaves were darker green and sometimes twisted and narrower than normal. Bunted plants also had a longer fruiting period, a condition particularly noticeable in durum varieties.

The majority of varieties mentioned in this paper have been described by Clark and Bayles (6), and nearly all of them are grown commercially in some part of the United States. A brief history and description of some of the resistant types not mentioned in previous publications is given here. Tisdale, *et al.* (15) tested the resistance of many wheat varieties to relatively innocuous collections of bunt at Davis, Calif., Moro, Ore., and Pullman, Wash., and reported the results in 1925. Some of their data are included in Table 2 for comparison, with results from more virulent races of bunt on the same varieties.

EXPERIMENTAL RESULTS

Table 1 gives the percentages of bunted heads in 250 wheat varieties grown in 1934 at Pendleton, Ore., from seed inoculated with a local and a Northwest composite of bunt collections. For convenience in presenting data, the common wheats are divided into commercial classes (hard red winter, hard red spring, soft red winter, and white). Data also are shown for varieties of club, durum, emmer, poulard, and Polish and for a wheat × rye hybrid.

HARD RED WINTER VARIETIES

The average infection for the entire group of hard red winter wheats was 63.6 and 74.9% from the local and Northwest composites, respectively. The reactions of several varieties are of interest.

When inoculated with the local composite, there were seven varieties (Ashkof, Hussar, Ioturk, Minturki, Oro, Ridit, and Yogo) in the group which developed less than 10% of bunted heads. Oro was the most resistant variety and produced only 1.3% of bunt. Cooperatorka, reported to be highly resistant to some collections (8, 10, 14), contained 23.8% of bunted heads from the local composite.

TABLE 1.—*Percentages of bunted heads in 250 wheat varieties grown in 1934 at Pendleton, Ore., from seed inoculated with a local and a Northwest composite of bunt collections.*

Variety	C. I. No.*	Percentage of bunted heads		Variety	C. I. No.*	Percentage of bunted heads	
		Local composite	Northwest composite			Local composite	Northwest composite
Hard Red Winter							
Alton	1438	94.2	97.4	Mosida	6688	88.7	94.6
Ashkof	6680	5.3	7.0	Nebraska No. 60	6250	94.5	95.3
Bacska	6156	74.3	91.5	Newturk	6935	93.3	90.7
Beloglina	1667	79.5	78.7	Oro	8220	1.3	0.4
Blackhull	6251	92.7	94.7	Quivira	8886	93.1	89.8
Cheyenne	8885	87.7	87.8	Redhull	11534	84.3	72.2
Cooperatorka	8861	23.8	92.8	Regal	7364	25.8	85.5
Eagle Chief	8868	90.1	93.1	Ridit	6703	4.5	18.9
Early Blackhull	8856	91.1	94.5	Rio	10061	26.1	20.4
Enid	11508	90.4	91.4	Sherman	4430	24.6	94.2
Hussar	4843	9.4	57.7	Superhard	8054	92.4	98.5
Iobred	6934	95.5	89.4	Tenmarq	6936	87.9	79.9
Ioturk	11388	8.1	94.6	Turkey	1558	92.9	94.1
Iowa No. 404	5580	95.8	93.0	Turkey sel	11424	18.0	23.4
Iowin	10017	94.1	95.1	Turkey sel	11425	84.0	89.1
Kanred	5146	83.9	74.6	Turkey X Bearded Minn. 48	8243	10.5	23.1
Karmont	6700	91.9	94.7	Utah Kanred	11608	86.3	96.1
Michikof	6990	96.5	94.8	Wis. Pedigree No. 2	6683	67.7	78.0
Minturki	6155	2.1	61.3	Yogo	8033	4.5	3.0
Montana No. 36	5549	92.7	89.9				
				Average		63.6	74.9
Hard Red Spring							
Alberta Early	10025	83.5	73.5	Marquis	3641	74.8	85.3
Bomen	8394	88.0	91.2	Marquillo	6887	88.2	87.8
Ceres	6900	94.6	92.7	Marvel†	8876	94.7	97.6
Champlain	4782	90.0	95.0	Missouri Valley	10046	87.8	93.4
Chul	2227	89.9	83.3	Montana King	8878	86.3	96.7
Converse†	4141	90.2	94.7	Prelude	4323	96.3	97.3
Fretes†	1596	97.5	90.3	Preston	3328	89.3	97.8
Garnet	8181	67.8	69.5	Power	3697	90.6	97.0
Ghirka	1517	92.3	95.7	Progress†	6902	94.9	85.0
Glyndon	2873	97.5	96.8	Red Bobs	6255	95.9	96.1
Haynes Bluestem	2874	95.1	93.4	Red Fife	3329	90.4	94.9
Hope	8178	78.4	83.5	Reliance	7370	88.9	89.9
Humpback†	3690	73.9	89.8	Renfrew	8194	86.4	91.9
Huston†	5208	99.0	98.7	Reward	8182	91.7	93.6
Java†	4966	80.6	74.2	Ruby	6047	38.7	91.3
Kitchener	4800	89.7	96.3	Sea Island	6551	85.9	81.0
Komar	8004	96.8	96.1	Stanley	4796	89.8	96.2
Kota	5878	95.7	97.3	Supreme	8026	92.6	93.5
Ladoga	4795	96.4	90.0	Whiteman	8379	94.5	94.2
				Average		88.3	91.1

*C. I. refers to accession number of the Division of Cereal Crops and Diseases.
†Kernels soft to semihard.

TABLE 1.—*Continued.*

Variety	C. I. No.*	Percentage of bunted heads: Local composite	Percentage of bunted heads: Northwest composite	Variety	C. I. No.*	Percentage of bunted heads: Local composite	Percentage of bunted heads: Northwest composite
			Soft Red Winter				
Ashland	6692	94.4	97.0	Nittany	6962	95.0	95.0
Baldrock	11538	95.7	95.5	Oakley‡	6301	93.8	88.9
Berkeley Rock	8272	20.9	90.3	Odessa	4475	25.1	92.4
Cherokee	11405	69.3	88.1	Penquite	5948	96.6	95.8
China	180	96.2	97.6	Poole	3488	98.8	98.4
Climax	6203	97.7	96.4	Portage	5654	98.4	93.2
Currell	3326	95.2	97.1	Prosperity	5380	98.3	93.6
Denton	8265	97.4	94.5	Purkof	8381	90.1	91.0
Diehl-Mediterranean	1395	91.6	89.2	Purplestraw‡	1915	98.7	96.0
Flint‡	6307	97.4	95.0	Red Chief	3392	82.7	93.8
Forward	6691	93.5	93.9	Red Clawson	3393	92.9	95.5
Fulcaster	4862	76.6	96.8	Redhart‡	8898	96.8	98.6
Fulhio	6999	97.5	99.4	Red Indian	8382	98.7	99.1
Fultz	1923	97.5	97.5	Red May	5336	98.0	96.3
Gasta‡	11398	97.2	95.5	Red Rock	5597	96.6	91.6
Gipsy	3436	96.4	96.8	Red Russian	4509	88.2	92.8
Gladden	5644	94.3	98.2	Red Wave	3500	92.4	96.7
Goens	4857	96.8	93.0	Rice	5734	97.5	95.2
Gold Drop	6316	96.1	97.6	Rochester	5693	96.2	97.6
Golden Cross	5180	95.8	97.0	Rudy	4873	94.6	94.8
Harvest Queen	5314	98.1	97.2	Ruddy	6465	93.3	92.8
Hohenheimer	11458	4.2	0.6	Rupert	5920	80.4	95.0
Hosar	10067	5.9	1.6	Rural New Yorker No. 6	5921	89.8	92.8
Hussar × Hohenheimer sel.	10068 1	0.9	0.3	Russian	5737	93.8	95.1
Illini Chief	5406	95.8	94.3	Russian Red	5928	96.6	97.7
Imperial Amber	5338	97.1	95.9	Shepherd	6163	91.6	92.3
Jones Fife	4468	98.5	96.0	Sibleys No. 81	10084	67.6	52.7
Kawvale	8180	88.5	91.8	Silversheaf	2496	91.9	92.7
Kinney‡	5189	90.2	96.6	Sol	6009	97.1	93.8
Kruse	11524	91.1	92.7	Triplet	5408	94.5	95.8
Leap	4823	95.1	97.2	Trumbull	5657	97.3	94.7
Lofthouse	3275	84.8	94.7	Valley	5923	96.7	98.0
Mammoth Red	2008	92.7	96.8	V. P. I. 112	11397	94.8	91.7
Mealy	3358	96.7	96.7	V. P. I. 131	10047	97.2	93.1
Mediterranean	5303	64.9	91.1	Walker	6445	94.6	98.3
Minhardi	5149	77.9	79.5	Wheedling	4816	97.7	92.4
Nabob	8869	95.3	95.5	Zimmerman	2907	98.3	98.4
Nigger	5366	99.8	94.7				
				Average		88.1	90.4
			Common White				
Allen	5407	95.9	92.0	Axminster	8195	55.5	85.3
Arcadian	4220	93.1	92.4	Baart	1697	92.4	89.5
Arco sel. 7	——	89.2	80.5	Baringa	——	87.5	91.6

*C. I. refers to accession number of the Division of Cereal Crops and Diseases.
‡Intermediate habit of growth.

TABLE 1.—*Continued.*

Variety	C. I. No.*	Percentage of bunted heads: Local composite	Percentage of bunted heads: Northwest composite	Variety	C. I. No.*	Percentage of bunted heads: Local composite	Percentage of bunted heads: Northwest composite
Common White							
Bunyip	5125	91.0	88.7	Martin	4463	14.0	93.6
Currawa	4982	85.6	93.7	New Zealand	6011	94.8	90.2
Dawson	3342	94.3	92.0	Onas	6221	91.9	89.1
Defiance	6477	93.6	93.4	Oregon Zimmerman	7359	94.6	92.8
Democrat	3384	97.8	98.8	Oro sel. 0535	——	6.7	82.5
Dicklow	3663	96.1	93.8	Pacific Bluestem	4067	92.1	95.2
Early Defiance	6480	90.9	89.5	Palisade	4798	94.5	94.9
Eaton	4682	92.8	91.8	Pilcraw	5540	94.1	93.8
Emerald	4397	93.0	92.2	Powerclub	8276	93.9	91.9
Escondido	8240	96.8	86.1	Prohibition	4068	97.7	95.9
Federation	4734	93.4	90.6	Propo	1970	95.1	96.1
Florence	4170	49.9	58.8	Pusa No. 4	8899	91.7	86.2
Foisy	5246	94.1	91.3	Quality	6157	33.0	70.3
Galgalos	2398	85.2	89.1	Regenerated Defiance	3703	94.4	94.9
Genesee Giant	1744	92.0	91.7	Rex sel.	11689	52.8	96.1
Goldcoin	4156	94.0	94.3	Rex sel	11690	69.4	93.9
Golden	10063	94.1	92.8	Rink	5868	97.8	97.7
Greeson	6320	95.1	96.8	Sevier	6247	94.2	78.9
Gypsum	4762	95.1	92.2	Silvercoin	6013	90.7	90.9
Hard Federation	4733	90.0	83.6	Sonora	3036	92.0	93.7
Hard Federation 31	8255	91.5	91.5	Surprise	2986	93.8	96.3
Hard Federation × Martin	11691	34.0	93.3	Thew	5002	92.8	94.1
Hard Federation × Martin	11692	45.5	94.8	Touse	6017	88.1	92.2
Honor	6161	94.1	91.3	Warchief	——	95.8	90.1
Indian	4489	92.8	96.8	Wilhelmina	11389	57.2	58.6
Kofod	4337	86.9	89.2	White Federation	4981	84.7	80.5
Longberry No. 1	5823	93.0	94.8	White Odessa	4655	49.8	91.2
Martin	4636	94.3	97.3	White Winter	5219	92.4	94.8
				Average		83.9	90.3
Club							
Albit	8275	21.1	96.1	Hybrid 128 × Martin	11606	39.7	93.3
Big Club	4257	91.1	98.6	Hybrid 128 × White Odessa	11607	46.9	97.9
Bluechaff	5256	95.4	98.4	Hymar	11605	43.1	94.5
Coppei	3088	80.4	84.8	Jenkin	5177	82.2	92.4
Genro	11535	92.5	92.2	Little Club	4066	95.2	93.0
Hood	11456	85.4	95.1	Mayview	5874	96.5	95.8
Hybrid 63	4510	93.7	94.5	Poso	8891	90.9	92.2
Hybrid 123	4511	88.4	96.2	Redchaff	4241	95.5	98.8
Hybrid 128	4512	96.9	91.2				
Hybrid 143	4160	95.4	92.5				
				Average		79.5	94.3

*C. I. refers to accession number of the Division of Cereal Crops and Diseases.

TABLE 1.—*Concluded.*

Variety	C. I. No.*	Percentage of bunted heads: Local composite	Percentage of bunted heads: Northwest composite	Variety	C. I. No.*	Percentage of bunted heads: Local composite	Percentage of bunted heads: Northwest composite
Durum							
Acme	5284	87.8	86.7	Marouani	1593	55.2	47.7
Akrona	6881	82.9	68.0	Monad	3320	91.4	87.3
Arnautka	1494	82.2	86.7	Mondak	7287	81.2	76.5
Barnatka	8214	90.1	77.5	Mindum	5296	75.9	76.2
Golden Ball	6227	12.4	29.3	Nodak	6519	94.2	87.2
Kahla	5529	78.2	77.6	Peliss	1584	76.4	53.9
Kubanka	1440	76.1	77.6	Pentad	3322	93.3	93.0
				Average		77.0	73.2
Minor Wheat Species and Wheat×Rye							
Alaska (poulard)	5988	90.7	81.9	White Polish (Polish)	3007	96.9	81.2
Vernal (emmer)	1524	76.2	76.4	Wheat×Rye	11403	1.0	1.8
				Average			

*C. I. refers to accession number of the Division of Cereal and Crops Diseases.

Oro likewise was the most resistant variety of the group when the Northwest composite was the source of inoculum. In other tests Oro has shown a heavy infection of smut, indicating that at least one race is present in the Pacific Northwest to which it is susceptible. There was 18.9% of bunt in Ridit, a variety highly resistant to many races. Such varieties as Minturki, Hussar, and Ioturk were heavily infected, although they were resistant to the local collections. There was a marked difference in pathogenicity of the two composites. For example, the infection in Minturki was 2.1% with the local composite and 61.3% with the more virulent Northwest composite. Rio, Turkey sel. (C. I. 11424), and Turkey × Bearded Minn. 48 (C. I. 8243) were moderately resistant to both composites. The history of the latter variety was given by Bressman (3). The Turkey was selected at the Kansas Station from a Crimean wheat (Kans. No. 373).

HARD RED SPRING VARIETIES

Ruby and Garnet proved most resistant of the hard red spring wheats to the local composite, although they were infected 38.7 and 67.8%, respectively. Aamodt (1) stated that Garnet was the most resistant variety commonly grown in western Canada, but he found it highly susceptible to some races of bunt. Ruby was very susceptible to the inoculum in the Northwest composite, but Garnet remained moderately resistant. Hope, known to be resistant to certain races (2, 8), was highly susceptible to the collections in these trials. The average infection for all hard red spring varieties was 88.3% with the local composite and 91.1% with the Northwest composite.

SOFT RED WINTER VARIETIES

Berkeley Rock and Odessa were the only commercial varieties in the soft red winter group showing any appreciable resistance in these trials. They were fairly resistant to the local composite but proved very susceptible to the Northwest composite. Hussar × Hohenheimer selection, Hohenheimer, and Hosar, none of which is grown commercially in the United States, were highly resistant to both composites and should have distinct value as parents in a breeding program involving resistance to bunt. The Hussar × Hohenheimer selection (C. I. 10068-1) was the most resistant variety tested. This selection was made at the Pendleton Field Station in 1931 from a cross produced by H. M. Woolman at Corvallis, Ore. It is a winter variety with large soft red kernels, coarse awns, and glabrous white glumes. It is of no commercial value because of low yield, susceptibility to shattering and winter injury, and poor quality. It is valuable, however, from the breeding standpoint, as it apparently combines the resistance of both parents. Hosar is a selection from the same cross but is even less desirable agronomically and is less resistant to bunt. The average infection for all soft red winter varieties was 88.1% for the local composite and 90.4% for the Northwest composite of bunt collections.

COMMON WHITE VARIETIES

The average infections of white wheats from the local and Northwest composites were 83.9 and 90.3%, respectively, which shows them as a class to be slightly less susceptible than the hard red spring and soft red winter groups. Oro selection 0535 and Martin (C. I. 4463) showed distinct resistance to the local composite, but no variety in the group was highly resistant to the Northwest composite. Quality and Florence contained 33 and 49.9% of bunted heads, respectively, from inoculation with the local composite and 70.3 and 58.8%, respectively, from the Northwest composite. The Hard Federation × Martin selections, White Odessa, Axminster, and the Rex selections were moderately resistant to the local composite. Wilhelmina apparently possessed some resistance to bunt, but the results may be misleading since the variety did not tiller to any extent.

Oro selection 0535, selected by J. H. Christ at Sandpoint, Idaho, is a result of field hybridization between Oro and an unknown variety. The selection is awnless and produces white grain.

The Hard Federation × Martin and Rex selections were made at the Sherman Branch Station, Moro, Ore. The Hard Federation × Martin selections are late-maturing spring varieties, but the Rex selections have a winter habit of growth. The selections from both have soft white grain, glabrous brown glumes, and stiff straw, and are resistant to shattering and drought.

CLUB VARIETIES

Albit, Hymar, Hybrid 128 × Martin, and Hybrid 128 × White Odessa were partially resistant to the local composite, but all club varieties were decidedly susceptible to the Northwest composite. Al-

bit and Hymar are the only bunt-resistant club wheats grown commercially in the Pacific Northwest at the present time. The average infection of all club varieties was 79.5% from the local composite and 94.3% from the Northwest composite.

Hymar, described by Clark (5), was distributed by the Washington Agricultural Experiment Station in 1935. Hybrid 128 × Martin (C. I. 11606) and Hybrid 128 × White Odessa (C. I. 11607) were selected at the Sherman Branch Station, Moro, Ore., from crosses made at the Washington Agricultural Experiment Station. Hymar and Hybrid 128 × Martin were selected from the same cross. All three varieties are awnless, white-glumed club wheats with white grain and winter habit of growth.

DURUM VARIETIES

The local composite produced 77% of bunt and the Northwest composite 73.2% as averages for all durum varieties. Golden Ball and Marouani were the most resistant varieties in the group. The remaining varieties varied for susceptibility, but none produced less than 75% of bunted heads.

An interesting feature of the durum varieties was the way they reacted to climatic conditions in the spring. Durum wheat is not adapted to dry-land conditions in the Pacific Northwest and the plants usually do not tiller to any marked degree. In the spring of 1934, a heavy second growth of tillers appeared at the bases of the plants about the time early tillers were nearing the boot stage of growth. This probably was a result of unseasonably warm weather, since durum varieties tiller very little in years with normally cool spring temperatures. Culms and heads formed from this late growth never reached the height of the early tillers. A majority of the heads from late tillers were infected with bunt, while the early heads were almost invariably free from disease. The tendency for late tillers to be bunted also was observed in other moderately resistant wheats. These results support the conclusions of other investigators (7, 12) that climatic conditions after seedling emergence affect the development of bunt.

MINOR WHEAT SPECIES AND WHEAT × RYE

Only one variety each of poulard, emmer, Polish, and wheat × rye were included in the trials. Vernal (emmer) appeared slightly resistant to bunt, but Alaska (poulard) and White Polish (Polish) were highly susceptible. The wheat × rye, which is an amphidiploid found by Meister (9), was highly resistant to both the local and the Northwest composites, but the transfer of this resistance to an agronomically desirable wheat offers many complications.

COMPARISON WITH PREVIOUS RESULTS

The infection in 17 wheat varieties inoculated with the two collections of bunt and the infection reported by Tisdale, *et al.* (15) are given in Table 2. Several varieties highly resistant in the early trials were very susceptible in the present tests, indicating that the inoculum consisted of different races. The spores of each collection of

bunt were viable and caused high infection on Hybrid 128, a susceptible variety. Ridit was the only variety in the group that was not heavily infected by the Northwest composite.

TABLE 2.—*Summary of data showing the comparative susceptibility of certain resistant wheat varieties and selections to different collections of bunt.*

Variety	C. I. No.	Percentage of bunted heads		
		Published data*	Local composite	Northwest composite
Hybrid 128	4512	76.4	96.9	91.2
Bacska	6156	13.9	74.3	91.5
Beloglina	1667	9.8	79.5	78.7
Hussar	4843	0.0	9.4	57.7
Kanred	5146	9.6	83.9	74.6
Minturki	6155	0.1	2.1	61.3
Ridit	6703	Trace	4.5	18.9
Turkey	1558	7.1	92.9	94.1
Odessa	4475	29.7	25.1	92.4
Humpback	3690	25.6	73.9	89.8
Marquis	3641	30.4	74.8	85.3
Ruby	6047	11.5	38.7	91.3
Martin	4463	0.0	14.0	93.6
Quality	6157	4.4	33.0	70.3
White Odessa	4655	2.4	49.8	91.2
Alaska	5988	14.7	90.7	81.9
White Polish	3007	19.7	96.9	81.2

*Data taken from U. S. D. A. Bul. 1299. 1925.

DISCUSSION

It is difficult to classify wheat groups for bunt resistance because resistant varieties create exceptions within each group. In general, however, the data in these experiments agree with those of Tisdale, *et al.* (15) and Bressman (4) that the hard red winter and durum wheats are more resistant than soft red winter, hard red spring, common white, and club wheats. The greatest numbers of highly resistant varieties were found in the hard red winter and soft red winter groups. The use of resistant varieties by farmers, together with proper seed disinfection, offers an excellent means of controlling the increase of virulent physiologic races of bunt.

In trials of the relative resistance of wheat varieties to individual collections of bunt, it was noticed that a few heads of the Turkey variety usually were bunted, whereas Hohenheimer, Hussar, and Martin often are entirely free from bunt when inoculated with certain physiologic races. A partial explanation of this is the excessive tillering of the Turkey varieties in many years. It was evident in these experiments that late tillers were more likely to be bunted than those formed earlier.

SUMMARY

A total of 250 wheat varieties, including common, club, durum, emmer, poulard, Polish, and wheat × rye, were tested in 1934 at Pendleton, Ore., for resistance to a local and a Northwest composite of bunt collections differing distinctly in pathogenicity.

Hussar × Hohenheimer selection (C. I. 10068-1) was the most resistant variety in these trials.

Oro, Yogo, Ashkof, and Ridit were the most resistant varieties among the hard red winter wheats grown commercially in the United States. Several other varieties were highly resistant to the local composite. The infection in Minturki was 2.1% with the local composite and 61.3% with the Northwest composite.

Ruby and Garnet proved most resistant of the commercial varieties of hard red spring and Berkeley Rock and Odessa of the soft red winter varieties.

None of the commercial varieties of white wheat was highly resistant but Quality, White Odessa, and Axminster were the least susceptible. Albit and Hymar were the only commercial club wheats not highly susceptible to all bunt collections.

Golden Ball and Marouani showed more resistance than the other durum varieties. Vernal (emmer) appeared slightly resistant, but Alaska (poulard) and White Polish (Polish) were highly susceptible.

The hard red winter and durum wheats were more resistant to bunt than the other classes of wheat, although resistant varieties created exceptions within each class. The greatest number of highly resistant varieties was found in the hard red winter and soft red winter groups.

Unseasonably warm spring temperatures stimulated a second growth of tillers in the durum wheats. Most of the late tillers produced bunted heads, although the heads on early tillers were free from disease. The tendency for late tillers to be bunted also was observed in other moderately resistant wheats.

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NOTE

A REAGENT FOR THE ELIMINATION OF THE INFLUENCE OF HIGH AMMONIA CONCENTRATIONS UPON THE POTASH RESULTS IN SHORT CHEMICAL SOIL TESTS

MOST of the short chemical tests for available potassium in soils are based on the reaction between sodium cobaltinitrite and a potassium salt to form the dipotassium sodium cobaltinitrite which is precipitated in more or less colloidal form by means of an alcohol and the resulting turbidity measured by a variety of procedures. Ethyl, methyl, and isopropyl alcohols have been used to effect the precipitation.

While all investigators[1] of the cobaltinitrite method for potassium in soils recognize the possibility of interference from the ammonium ion, there is a lack of definiteness as to the extent of this influence, except for the statement by Bray that the test as carried out under his conditions is approximately four times as sensitive to the potassium ion as it is to the ammonium ion.

Under carefully defined conditions, as would be encountered in the use of the sodium cobaltinitrite test for potassium in soils by the short chemical method, the influence of the ammonium ion and the use of different alcohols has been investigated, and the reaction described by Macallum for the elimination of ammonium salts in the cobaltinitrite reaction for potassium has been applied to these tests.

While ethyl alcohol has been found to be the most satisfactory alcohol (of ethyl, methyl, and isopropyl), relatively large amounts of ammonia nitrogen in the soil extract distinctly deviate the results. A reagent for eliminating the influence of ammonia in the short chemical tests is very highly desirable. Formaldehyde substituted for a part of the alcohol in the test eliminates the interference of a high test of ammonia. Two milliliters of 37% formaldehyde supplied before the alcohol is added completely ties up the ammonia and prevents its

[1]BRAY, R. H. A test for replaceable and water-soluble potassium in soils. Jour. Amer. Soc. Agron., 24:312–316. 1932.
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precipitation when the alcohol is added. The formaldehyde takes the place of two mls. of the alcohol in the method described by Hester and is added extra in the LaMotte procedure.

In preliminary experiments made by Hester, this reagent was added to eliminate ammonia in the regular potash method described by Schueler and Thomas. The results were not entirely satisfactory, and it was indicated that further work will be necessary in order to determine definitely whether or not the reagent is applicable to this particular procedure. This, however, does not eliminate its use in the short chemical soil tests. Since ammonium salts combine with formaldehyde to form hexamethylenetetramine, it removes the ammonia from the solution sufficiently well to prevent it from interfering with the short chemical tests as they are normally conducted.—

W. R. KENNY, *LaMotte Chemical Products Co., Baltimore, Md., and* JACKSON B. HESTER, *Virginia Truck Exp. Station, Norfolk, Va.*

BOOK REVIEWS

SOIL SCIENCE: ITS PRINCIPLES AND PRACTICE

By Wilbert W. Weir. Chicago: J. B. Lippincott Co. XII + 615 pages, illus. 1936. $3.50.

THIS book consists of a very comprehensive and clearly written discussion of soils, their handling, fertilization, and relation to plant growth. It is perhaps a little unfortunate that the title of the book is the same as that of a well-known American periodical; yet aside from the possibility of confusion this may cause, the title well suits the subject treated. A considerable amount of scientific data is given, but the language is not highly technical and should be easily understood by laymen as well as practical workers and college students.

The book is divided into 27 chapters which are not arranged under more comprehensive headings. Upon glancing over them, however, they seem to group themselves somewhat as follows: A single chapter on historical development of the subject; 4 chapters (about 50 pages) on soil physics, chemistry, and microbiology; 3 chapters (about 60 pages) on soil classification, including a readily understood resumé of modern conceptions as based on the Russian system of classification; 10 chapters (about 225 pages) on crop production as affected by various soil factors; and 8 chapters (about 200 pages) on fertilizers and crop rotation in its relation to soil fertility, including a chapter on soil erosion and its control.

The book is well illustrated and some of the photographs showing different types of soil practice are extremely interesting. Special mention perhaps should be made of the 40-page index with which the book is concluded. (H. J. C.)

BODEN UND PFLANZE

By Sir E. John Russell. Leipzig: Verlag von Theodor Steinkopff. Second German edition. (Translation by Dr. K. W. Müller of 6th English edition.) 446 pages, illus. 1936. Unbound, RM 30; bound, RM 32.

THIS is a German translation of Sir E. John Russell's well-known book *Soil and Plant Growth*. It is preceded by a foreword by Georg Wiegner, but otherwise is essentially the same as the English version except that it contains a more detailed table of contents. (H. J. C.)

AGRONOMIC AFFAIRS

MEETING OF WESTERN BRANCH OF SOCIETY

WEEDS and forage crops were the main topics discussed at the Twentieth Annual Meeting of the Western Branch of the American Society of Agronomy at Pullman, Washington, and Moscow, Idaho, June 22, 23, and 24, 1936. A number of papers, however, were given on cereals and general agronomic topics. Titles for 22 papers were submitted in advance and 4 additional papers were given. The 70 persons registered were mainly agronomists and came from 8 of the 11 western states and from the U. S. Dept. of Agriculture.

Mornings were filled with a program of papers and discussions, while afternoons were devoted to observation trips. On the trips the visitors were taken over the soil conservation nurseries and soil conservation experiment station fields, the Washington and Idaho Experiment Station farms, and the Washburn-Wilson pea-breeding grounds. The banquet the second evening was attended by a number of guests as well as agronomists.

B. B. Bayles of the U. S. Department of Agriculture Cereal Office was elected President, succeeding R. S. Hawkins; and Clyde McKee of the Montana State College Agronomy Department was elected Secretary, succeeding E. G. Schafer. The 1937 meetings are to be held at Bozeman, Montana.—E. G. SCHAFER, *Secretary*.

TOBACCO FERTILIZER RECOMMENDATIONS FOR 1937

RECOMMENDATIONS for fertilizing flue-cured, sun-cured, and shipping tobacco grown on the average soils of Virginia, North and South Carolina, and Georgia during 1937 are now available in mimeographed form. The recommendations have been formulated by a committee made up of representative agronomists from these states and from the U. S. Dept. of Agriculture, with Prof. C. B. Williams of North Carolina Agricultural Experiment Station, Chairman, and Prof. T. B. Hutcheson of the Virginia Agricultural Experiment Station, Secretary. Suggestions to agricultural workers for formulating recommendations for the control of downy mildew and root-knot of tobacco, prepared by representatives of the Tobacco Disease Research Council, are also included in the mimeographed report.

FILM STRIP SERVICE

PRICES for film strips issued by the U. S. Dept. of Agriculture will be approximately the same for the fiscal year 1936–37 as those in effect during the past year. Dewey & Dewey, Kenosha, Wis., have again been awarded the contract for film-strip production.

The majority of the 275 series of film strips available will sell for 50 or 65 cents each. Film strips are available on such subjects as farm crops, dairying, farm animals, farm forestry, plant and animal diseases and pests, farm economics, farm engineering, home economics, and adult and junior extension work. Lecture notes are provided with each film strip purchased. A list of available film strips and instructions on how to purchase them may be obtained by writing to the Division of Cooperative Extension, U. S. Dept. of Agriculture, Washington, D. C.

PLANT BREEDING ABSTRACTS

THE Imperial Bureau of Plant Genetics at Cambridge, England, announces the publication of a Supplement to *Plant Breeding Abstracts*, dealing with reports from stations in the British Empire for the period of 1932 to 1935 The Supplement is intended to give a concise account of plant breeding work and related topics carried on within the British Empire during the period indicated and involved the scrutiny of over 400 reports.

Much of the work referred to is only available in annual reports, being more or less of a routine nature. Another valuable feature of the Supplement is that many of the items included concern work which, though likely to be published in the future, has not yet reached that stage.

The crops dealt with cover practically the whole range of economic plants, with the exception of herbage plants, and the work reported includes breeding, genetics, and cytology. There is also a section on the genetics of plant parasites

The Supplement is planned in such a way that the work on a given crop in a given country can be turned up at once An extensive index is also provided. A similar supplement is now in process of compilation from reports received from foreign stations.

NEWS ITEMS

DR. D. F. JONES, head of the Department of Plant Breeding at the Connecticut Agricultural Experiment Station, has returned to New Haven following a year's leave of absence for special research at the California Institute of Technology at Pasadena.

JOHN W. GILMORE, Professor of Agronomy in the University of California, has been elected to honorary membership in the Faculty of the University of Chile and in recognition of his election has been granted a diploma. Professor Gilmore was invited by the Government of Chile to act as consultant on matters of classification and management of land under a deficient and seasonal rainfall. He left for Chile in February and returned to his work in California on August 1.

FIVE STUDENTS majoring in soils received the degree of Doctor of Philosophy from the University of Wisconsin at Commencement in June this year. Their names and respective appointments for the coming year are as follows: Charles D. Jeffries, Assistant Professor of Soil Technology, Pennsylvania State College; Adolf Mehlich, Research Assistant, Boyce Thompson Institute for Plant Research; Robert J. Muckenhirn, Instructor in Soils, University of Wisconsin; Otto E. Sell, Pasture Research, Georgia Experiment Station; and Garth W. Volk, Assistant Professor of Soils, Oklahoma A. and M. College.

THE AMERICAN POTASH INSTITUTE, INC., announces the appointment of Dr. H. B. Mann as manager of its southern territory, the position left vacant by the recent death of Dr. J. N. Harper. Since the first of this year, Dr. Mann has been assistant manager, coming to the Institute from the North Carolina Agricultural Experiment Station where he had served for several years as agronomist in soil fertility work.

THE FIRST book to be published by the newly established Rutgers University Press is a volume entitled "Pedology" by Dr. J. S. Joffe, research chemist in soils at the New Jersey Agricultural Experiment Station. A review of the book will appear in an early number of the JOURNAL.

PROFESSOR WILLIAM J. SQUIRRELL, head of the Department of Field Husbandry of the Ontario Agricultural College, was fatally injured in an automobile accident near Smithville, Ontario, on July 25. Professor Squirrell was responsible for the development of many new varieties of grains and was for many years Secretary of the Ontario Agricultural and Experimental Union.

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EFFECT OF SOURCE, QUALITY, AND CONDITION OF SEED UPON THE COLD RESISTANCE OF WINTER WHEATS[1]

C. A. SUNESON AND GEORGE L. PELTIER[2]

THE technic for the determination of comparative hardiness in winter wheats by controlled freezing is still in the formative stage. In the literature hardening responses form the major interest. The writers (6)[3] have already shown, however, that the stage of plant development may greatly affect the relative hardiness of winter wheat varieties. Likewise, observations over a period of years have indicated that source and quality factors in seed might modify winter hardiness comparisons. There is a sufficient body of literature contrasting individual plant development, growth, and disease reactions to suggest an investigation of the effect of these factors. Thus, citing only a few typical references, Kiesselbach and Helm (2) have shown a 17% yield difference between individual progeny of large and small wheat seeds; and Koehler, Dungan, and Burlison (3), working with five seedling diseases in corn, found that each fungus caused the greatest stand loss when applied to the most immature of several seed lots harvested at different stages of maturity. The work of Holbert (1) in pointing out an association between high soil fertility and plant hardiness also deserves consideration.

METHODS

In general, the technic employed was the same as that reported earlier (5, 6). Both field and greenhouse plants were used. In only a few instances were plants

[1]Based on cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Departments of Agronomy and Plant Pathology, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Journal series paper No. 178 of the Nebraska Agricultural Experiment Station. Received for publication June 15, 1936.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 692.

exposed to freezing temperatures before they had attained the five-leaf stage of development. Each flat was divided to include all of the units being compared, each with an equal exposure and random positional placement. Only comparable stands were considered. In the majority of instances this involved 25 plants of each variable in each of the eight flats frozen on each date. Exposures were for a constant period of 24 hours at temperatures commensurate with the season and habitat. Survivors were noted after a 2-weeks' recovery in a 70°F greenhouse. All experiments embraced comparisons over a period of two or more winter months.

RESULTS

EFFECTS OF SEED SOURCE UPON COMPARATIVE COLD RESISTANCE OF WINTER WHEAT SEEDLINGS

The first and most extensive seed-source comparison is listed in Table 1, experiment 1, and contrasts the progeny of five varieties (Blackhull, Cheyenne, Minturki, Nebraska No 60, and Tenmarq) from the 1933 seed crop produced at Lincoln, Nebr., and Bozeman,

TABLE 1.—*Comparative hardiness of winter wheat plants from seed differing in source and condition.*

Experiment No.	Variety	Source of seed	Condition of seed: Weight per 100 kernels, grams	Protein* %	Appearance	Average plant survival %
1	Average of 5 varieties	Bozeman, Mont.	3.41	16.5	Normal	48
		Lincoln, Nebr.	1.76	17.1	Shriveled	34
2	Nebraska No. 60	Ithaca, Nebr.	2.85	13.9	Dark	55
		Pender, Nebr.	2.70	12.2	Yellow berry	51
		Venango, Nebr.	1.99	16.4	Bright	48
		Seward, Nebr.	2.34	16.0	Weathered	44
3	Turkey Sel Nebr. No. 1069	Bozeman, Mont.	3.05	13.0	Bright	66
		Moccasin, Mont.	2.62	15.3	Dull	64
		Manhattan, Kan.	2.68	11.6	Bright	58
		Lawton, Okla.	1.94	15.0	Small kernels	50
4	Average of 2 varieties	Bozeman, Mont.	3.18	15.4	Yellow berry	47
		Moccasin, Mont.	2.94	16.5	Dull	44
		Alliance, Nebr.	2.45	13.8	Dull	41
		Lincoln, Nebr.	1.31	19.2	Shriveled	34
5	Cheyenne	Madrid, Nebr.	2.29	15.1	Bright	56
		Gladstone, Nebr.	2.87	11.9	Yellow berry	54
		Beatrice, Nebr.	1.39	21.4	Shriveled	54
		Pender, Nebr.	2.55	17.4	Weathered	39
6	Cheyenne	Waco, Nebr. (1935)	1.42	—	Weathered	43
		Lincoln, Nebr. (1929)	3.21	—	Yellow berry	63

*Analyses by Dr. M. J. Blish, Chemist, Nebraska Agricultural Experiment Station, Lincoln, Nebr.

Mont. The most conspicuous variable in the condition of the seed was the difference in size. Since the several varieties tested all reacted similarly, the percentages of survival have been averaged. Likewise, the sets grown in the field and greenhouse are averaged for the same reason, giving a total of 206 comparisons. The average survival difference of 14% is highly significant when tested by the binomial method (4). This difference in the survival of the same varieties originally from a common source, the seed of which was later obtained from two widely removed locations, equals the range commonly expected between broadly differentiated hard winter wheats, such as Blackhull and Nebraska No. 60. It should be pointed out that these and other seed stocks tested were later checked for type and purity under field conditions.

In experiment 2 (Table 1) four 1933 crop stocks of Nebraska-grown, certified Nebraska No. 60 wheat were compared. All of the plants were grown in the greenhouse and hardened under controlled conditions. Stages of plant development ranging from two to six leaves were averaged in this instance, giving a total of 52 comparisons. The seed from Seward, Nebr., was pronouncedly weathered and in occasional kernels the sprouts had broken through the pericarp, consequently producing plants distinctly inferior in cold hardiness to the very attractive seed from Ithaca, Nebr.

A comparison of seed of Turkey selection, Nebraska No. 1069, produced at four points in 1934, is listed in Table 1, experiment 3. The 1933 parent seed stock was produced at Lincoln, Nebr. A survival difference of 16% was recorded between the lots grown at Bozeman, Mont., and Lawton, Okla.

In experiment 4 (Table 1) Blackhull and Nebraska No. 60 grown at four locations in 1934 from seed produced at Manhattan, Kan., were compared. The seedlings included in both experiments 3 and 4 were field grown and in the five- to eight-leaf stage when compared for hardiness at successive dates from November through February. The plants produced by the smaller kernels were less hardy in both trials, each of which included 16 comparisons. Approximately the same relationship was maintained in the seed produced at Moccasin and Bozeman, Mont., even though the varieties were different.

Certified seed stock of Cheyenne, the parent seed of which was produced the previous year at Lincoln, Nebr., was compared in experiment 5 (Table 1). The seedlings were grown in the greenhouse and later exposed to low temperatures from 25 to 32 days after emergence, which was well beyond the period of direct endosperm dependence. Some lots were hardened at a constant temperature (2° to 3°C), while others were frozen in a non-hardened condition. The averages shown were derived from 32 comparisons. The field-weathered seed produced plants inferior in hardiness, but the plants from small seed apparently were at no great disadvantage with respect to hardiness.

Seedlings from two field-grown seed stocks of Cheyenne were frozen at intervals from November through January in a total of 48 tests. The data are given in experiment 6 (Table 1). In this instance old seed (1929 crop), despite some loss in germinating power, pro-

duced plants which were materially more hardy than those obtained from a badly rusted field of the current crop (1935).

A review of the six experiments reported in Table 1 shows that differences in survival of from 11 to 20% were observed in these source of seed comparisons. These differences between high and low survival stocks are all highly significant when tested by the binomial method (4).

EFFECT OF SEED QUALITY AND CONDITION UPON COMPARATIVE COLD RESISTANCE OF WINTER WHEAT SEEDLINGS

In the above experiment, which very positively pointed to seed variation as a potential source of variation in hardiness reactions within the same variety, three readily recognizable factors in seed condition or quality were suggested, i. e., size, weathering, and protein content.

One of the several preliminary field comparisons bearing on size of seed involved contrasting seed from Lincoln, Nebr., plantings made September 20 and October 20. Seed of three varieties employed differed by 0.7 gram per hundred kernels in weight. The plants in turn differed by only 2% in survival, based on 48 replications. This difference in survival is not significant. The data moreover confirm an earlier field test in which 13 varieties harvested at the same two dates were compared. In this instance plants from the plumper seed were superior in 19, inferior in 17, and equal in 3 rows. Thus, it would seem that moderate seed-size differences do not significantly modify hardiness reactions.

When kernels were injured by halving or crushing, much smaller plants resulted than from normal ones. These differences in plant size exceeded any differences observed in connection with the experiments reported in Table 1. These plant size differences persisted throughout the winter months, during which time, however, the growth stages were comparable. In 48 comparisons involving both greenhouse and field-grown plants and extending over several months, plants from normal kernels showed an average survival of 57%, compared with 26% for the plants from the injured kernels. In only 4 of the 48 comparisons did the plants from normal kernels show a lower survival, a fact which emphasizes the significance of the hardiness differences.

A second factor is weathering of seed. In Table 1, plants from weathered seed were inferior in hardiness in three of the experiments. Confirmation of such a trend was also obtained in preliminary experiments. In Table 2 a comparison was made of plants of Kawvale × Tenmarq, C. I. No. 11669, from seed harvested July 16 and September 13, respectively. During the above interval the standing grain had not lodged but all the kernels had sprouted, so that the plumules had penetrated the pericarp slightly. Plants from this seed held a distinct advantage in hardiness until January 1, when a reversal occurred. The superiority before this date, as well as the inferior hardiness shown afterwards, was significantly different. Although no evidence of difference in growth stage was observed between the

plants from the two lots of seed, differences in plant development probably existed and vitally influenced the results.

TABLE 2.—*Comparative hardiness of plants of Kawvale × Tenmarq, C. I. 11669, grown from seed harvested at a 2-month interval.*

Condition of seed		Percentage survival during indicated months		Binomial frequency distribution (No. of times superior)	
Date of harvest	Appearance	November December	January February	November December	January February
July 16	Dark, bright	58	55	9	21
Sept. 13	Weathering, severe	71	50	22	10

A third possible variable can be readily recognized in Table 1 where protein contents between seed stocks from varied sources, even in the same variety, were marked. The results of an experiment contrasting dark hard and yellow berry kernels of equal weight from three different varieties are listed in Table 3. Both types of seed of each of the varieties reacted to cold in approximately the same degree, so this variable is probably not important.

TABLE 3.—*Comparative hardiness of plants from dark, hard, and yellow berry seed of three winter wheats, all from a common source.*

Variety	Type of seed	Average plant survival %	Bionomial frequency distribution (No. of times superior)	
Turkey Sel., Nebr. No. 1069	Dark, hard	31	15	—
Turkey Sel., Nebr. No. 1069	Yellow berry	31	—	16
Cheyenne..................	Dark, hard	65	25	—
Cheyenne..................	Yellow berry	62	—	25
Nebraska No. 60............	Dark, hard	82	17	—
Nebraska No. 60............	Yellow berry	83	—	22

Failure to account for most of the differences noted in the source of seed comparisons in Table 1 does not remove the problem. The practical aspects of the problem are well illustrated in Tables 4 and 5. With seed of like quality, all produced at one location, hardiness comparisons in close agreement with normal field relationships can be expected (Table 4). When plants grown from seed of different ages, of unlike origin, and of varying quality and condition are compared for hardiness, the results may be extremely erratic (Table 5). The plants grown in 1935-36 did not reach the early tillering stage of development until late in November, which probably accounts for the greater advantage for large seeds early in November (6). Regardless of stage of early plant development, however, these experiments very positively recommend the use of seed comparable as to origin, quality, and condition in all winter hardiness studies.

TABLE 4.—*Comparative hardiness of field-grown plants of winter wheat varieties from seed with a common source and similar quality (1933–34).**

Variety	Percentage survival at indicated dates		
	Nov. 28–29	Jan. 10 11	Mar. 9–10
Honor	14	10	57
Cheyenne	45	20	93
Lutescens	60	42	98

*Sixteen comparisons averaged at each period

TABLE 5.—*Comparative hardiness of field-grown plants of three winter wheat varieties from seed of varying age, source, and quality (1935–36).**

Variety	C. I. No.	Year produced	Source of seed	Condition of seed		Percentage survival at indicated dates					
				Weight per 100 kernels, grams	Chief factor responsible for light weight kernels	Nov. 8	Nov. 22	Dec. 5	Dec. 19	Jan. 2	Jan. 22
Honor	6161	1935	Rosslyn, Va.	3.44	None	57	39	56	67	55	60
Cheyenne	8885	1933	Lincoln, Nebr.	2 16	Chinch bugs	21	30	59	67	54	73
Lutescens	8896	1935	North Platte, Nebr.	86	Stem rust and heat	12	24	63	65	49	68

*Eight comparisons averaged at each period. Technic similar as in the hardiness studies reported in Table 4.

SUMMARY

Winter wheat seedlings, some grown in the field and some in a greenhouse and mostly in the five- to eight-leaf stage of development, gave highly significant hardiness differences within the same varieties when different sources of seed were compared.

Several specific variates, such as seed size, weathering, and protein content, were tested to establish their relationships to differences in hardiness. Variables such as seed size and protein content gave no consistent differences, while post-maturity factors, such as sprouting, weathering, or severe mechanical injury, gave significant differences in hardiness. The latter results extend the scope of seed variations, but fail to account for most of the differences in hardiness observed in the regional collections of the common winter wheat varieties considered.

This subject deserves extended study because of the large variations obtained in comparative hardiness with small grains, especially with seed produced under unlike environments.

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A METHOD FOR STUDYING RESISTANCE TO DROUGHT INJURY IN INBRED LINES OF MAIZE[1]

JAMES W. HUNTER, H. H. LAUDE, AND ARTHUR M. BRUNSON[2]

CORN production in the Great Plains area frequently is limited by periods of extremely high temperature accompanied by low humidity and deficient soil moisture in midsummer. Under such conditions it is necessary to consider the relative tolerance to drought and high temperatures of various strains in a corn improvement program. Wide variations in weather conditions from year to year make testing of this relative tolerance under field conditions very uncertain as stress periods may not occur in a given year or even in a succession of several years. It would therefore be highly desirable to have a simple and reliable technic for testing strains under controlled conditions.

Very little work has been reported on the comparative injury of plants by high temperature under controlled conditions. Shirley[3] reports a method for studying drought resistance in which the plants (*Picea canadensis*) were placed in an illuminated chamber. The temperature was controlled by a thermo-regulator and the air was passed over calcium chloride as a dehydrating agent. The length of time each plant survived was used as a criterion of its drought resistance.

Aamodt[4] describes an apparatus for testing the resistance of wheat plants to hot drying winds. A constant temperature was maintained in a glass wind tunnel by thermostatically controlled electric heaters, and the rate of flow of the air current was regulated by baffles and sliding doors. After exposure for 8 to 15 hours to a 6-mile per hour air current at 110°F, wheat varieties showed differential injury paralleling that observed under natural conditions of severe atmospheric drought in the field.

MATERIALS AND METHODS

Drought tolerance in certain strains and susceptibility to injury by drought in others are manifested clearly in the corn breeding nursery at Manhattan, Kansas, nearly every year. Some strains have the ability to endure long periods of drought with little or no injury, while other strains are injured under much less rigorous conditions. Eight inbred lines of maize chosen on the basis of their behavior under field conditions in the corn improvement project of the Kansas Agricultural Experiment Station were used in these experiments. These lines represented a

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[3]SHIRLEY, HARDY L. A method for studying drought resistance in plants. Science, 79:14–16. 1934.

[4]AAMODT, O. S. A machine for testing the resistance of plants to injury by atmospheric drought. Can. Jour. Res., 12:788–795. 1935.

range in drought reaction from susceptible to resistant. In observing these lines in the field during several seasons it was noted that they reacted in different ways. In some susceptible lines the first indication of injury, designated as "top-firing", was the blasting of the tassel and usually the wilting of the top leaves. Other susceptible lines, in which the injury was referred to as "base-firing", fired progressively from the bottom of the plant upward. In still other lines, known as "resistant", obvious evidence of heat injury was deferred until after the susceptible lines were badly fired. The reactions in the field of the eight inbred lines for the four summers, 1931–34, representing a succession of unfavorable years, are shown in Table 1.

TABLE 1.—*Observations under field conditions of eight inbred lines of corn grown on the Kansas Agricultural Experiment Station, 1931–34.*

Line No.	Pedigree No.	Reaction*			
		1931	1932	1933	1934
4	9813	R	R	R	R
6	10448	R	R	Bf	R
5	10391	R	R	R	R
8	9802	Tf	Tf	Tf	Tf
3	9019	Tf	Tf	Tf	Tf
7	10423	R	R	R	Tf
9	10438	Bf	Bf	Bf	Bf
10	9842	Bf	Bf	Bf	—

*Tf = Top-firing; Bf = Base-firing; and R = Resistant.

It is generally recognized that the time of flowering is a critical period in the life of the maize plant and that the plant is particularly susceptible to drought injury at this stage. If the lines to be compared differ markedly in time of flowering, some may encounter short periods of adverse weather at a more critical stage of development than others. Among the strains considered in this study, however, such differences in injury were not important, as all of the lines flowered at about the same time.

A simple heat chamber with thermostatically controlled electrical heating units was used in the artificial tests. A small fan kept the air in constant motion and insured uniform temperatures throughout the chamber. Although no attempt was made to regulate the moisture, a recording psychrometer kept in the chamber indicated that the relative humidity remained between 28 and 32% at the operating temperature. Fourteen-day-old seedlings grown under comparable conditions in 4-inch clay pots were placed in the chamber at 140°F for 6.5 hours.

EXPERIMENTAL RESULTS

In the first controlled experiment, made December 1, 1934, the soil was brought to an optimum moisture content before being placed in the heat chamber. At the high temperature the soil dried rapidly and at different rates in the various pots. These differences in soil moisture, though slight, appeared to be a factor in the results. Therefore, in the succeeding tests, the soil first was saturated and the pots were placed in a shallow tray of water during the experiment. The experiment was repeated four more times between December 12, 1934, and February 13, 1935. Following each test, the inbred lines

were arranged in order of injury sustained from least to greatest, as shown in Table 2. The results of the various replications, except those of the test on December 1, were extremely uniform, considering the fact that it was impossible to control the relative humidity accurately. Both under controlled conditions and in the field, lines 4, 5, 6, and 8 always showed less injury than lines 3, 7, 9, and 10.

TABLE 2.—*Relative injury to eight inbred lines of corn by artificially produced high temperatures compared with exposure to drought in the field.*

Date	Treatment	Line numbers arranged in order of injury from least to greatest
Dec. 1, 1934 ..	Heat chamber	6-5-4-8-9-3-10-7
Dec. 12, 1934..	Heat chamber	4-6-5-8-3-7-9-10
Dec. 28, 1934..	Heat chamber	4-6-8-5-3-7-9-10
Jan. 11, 1935..	Heat chamber	4-6-5-8-3-7-9-10
Feb. 13, 1935 .	Heat chamber	4-6-5-8-3-7-9-10
1934 season...	Drought conditions in the field	4-6-5-8-3-7-9-10

Inbred lines 4 and 6, which were the most drought resistant strains under field conditions, resisted high temperature to a very marked degree and showed practically no injury in the last four tests. When placed under good growing conditions after removal from the chamber these lines recovered completely. Lines 5 and 8, which are moderately resistant to drought under field conditions, indicated marked resistance to high temperature and when returned to good growing conditions from 50 to 75% of the plants recovered. Lines 3 and 7, top-firing under field conditions, developed injury to the tips of the leaves in 3 hours and were severely wilted within 6.5 hours. When placed under good growing conditions, from 0 to 25% of the plants recovered. Line 9, a base-firing type, resisted the high temperature to a marked degree for a period of 5 hours during which there was little or no apparent injury. Injury then developed quickly, however, and the plants appeared to be dead at about 6 hours. None of them recovered when placed under good conditions for growth. Line 10, which was the most susceptible to drought injury in the field, was killed by the high temperature treatment within 6 hours. Although line 10 was not grown in the field in 1934, its behavior the previous three summers showed beyond question that it was the most susceptible to heat and drought injury of any of the eight lines considered

It may be noted that the lines susceptible to base-firing resisted injury by high temperature for a longer time than those susceptible to top-firing, but succumbed more quickly after injury became apparent.

The conditions of the plants 3 days after exposure to the high temperature is shown in Fig. 1. The pots bearing numbers which correspond to the numbers of the inbred lines tested are arranged in order of increasing injury from 4 to 10. Line 4 shows no appreciable injury. In inbred 6, the leaf tips were injured slightly. The tops of the plants in line 5 were injured about 50%. Line 8 also shows about 50% injury which affected more of the plant. The plants of line 3 were practically dead, and those of inbreds 7, 9, and 10 were dead.

FIG. 1.—Comparative injury to inbred lines of corn caused by exposures for 6.5 hours to a temperature of 140°F and a relative humidity of 30%. Each pot is representative of the line indicated by the number.

The close relative correspondence between injury of large plants in the field and injury to 14-day-old seedlings in the heat chamber indicates that the latter method may be of value in testing inbred lines, hybrids, or open-pollinated varieties under controlled conditions. Almost perfect agreement was obtained in the progressive order of field injury during the severe season of 1934 as compared with the order obtained with seedlings in the heat chamber. The ability to distinguish lines resistant to heat and drought injury by means of a simple test of seedling plants should prove of value to corn breeders where tolerance to hot dry conditions is an important factor.

SUMMARY

By testing 14-day-old seedlings for 6.5 hours in a chamber with temperature controlled at 140° F and with a relative humidity of about 30%, it was possible to distinguish among strains with respect to drought tolerance. Essentially the same order of relative resistance was obtained with the seedlings as was noted for the plants in the field.

The lines susceptible to top-firing under field conditions showed marked injury in the testing chamber in 3 to 5 hours, those susceptible to base-firing showed injury in 4 to 6 hours, and the resistant lines showed little or no injury after 6.5 hours. When returned to good growing conditions following the exposure to high temperature, the survival of plants was 0% in the lines susceptible to base-firing, 0 to 25% in those susceptible to top-firing, and 50 to 100% in the resistant lines.

RATES OF SEEDING WHEAT AND OTHER CEREALS WITH IRRIGATION[1]

Roy E. Hutchison[2]

ANY increase in yields that may be gained by varying the rate of seeding of grain is a relatively inexpensive advantage to the grower. Results of experiments reported have generally indicated that cereals have remarkable abilities of adaptation to their environment in occupying the land to the best advantage. Among the factors that affect yield, rate of seeding is supposed to be important.

McClelland (3)[3] concluded that slight differences in rates result whether seed be counted, weighed, or measured. Godel (1) from experiments with wheat on dry weedy land in Saskatchewan obtained better yields from 105 pounds of seed per acre than from 75 pounds. Stephens, Wanser, and Bracken (5) from experiments with wheat under dry-land conditions in the northwest found no great difference in yields from rates of seeding of 2 to 8 pecks per acre but concluded that 5 pecks was the optimum rate. Thatcher (6), working in Ohio, and Leighty and Taylor (2), from experiments at the Arlington farm in Virginia, have summarized considerable data on the rate of seeding wheat under more humid conditions. They obtained very little difference in yields from all rates of 60 pounds and over per acre. They concluded 90 pounds to be the optimum rate. Data of Sprague and Farris (4) indicate that the barley plant has considerable ability to modify its development in response to the soil resources available and that variability of the soil was far more important in determining yields than population density. They have reviewed considerable literature on the subject.

The object of the studies reported here was to obtain similar information for conditions of high altitude, short growing season, and under irrigation in central Oregon.

ENVIRONMENTAL CONDITIONS

The Harney Branch Experiment Station, located at Burns, Oregon, offers considerably different conditions from those which exist in most of the wheat-growing areas. The daily range in temperature is extreme. Freezing temperatures of 22° to 25° occur regularly as late as May 28 to June 5. The 22-year mean minimum temperatures for May, June, July, and August are 34°, 39°, 44°, and 42°, respectively. The mean maximum temperatures for the same months are 68°, 77°, 87°, and 85°, respectively. The 21-year average frost-free growing season is 64 days. There are many cloudless days. The precipitation and humidity are generally low. The average annual evaporation from a free water surface during the 7 months from April to October, inclusive, is 41.784 inches. The average precipitation from April 1 to July 31 for the years 1932 to 1935, inclusive, was 2.42 inches.

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[1]Contribution of the Harney Branch Experiment Station, Burns, Oregon. Published as Technical Paper No. 245 with the approval of the Director of the Oregon Experiment Station. Received for publication June 22, 1936.

[2]Assistant to the Superintendent.

[3]Figures in parenthesis refer to "Literature Cited", p. 703.

The average annual precipitation, September 1 to August 31, for the 4 years was 7.60 inches. An experiment was started in 1932, under these conditions, to compare various rates of seeding for cereals.

EXPERIMENTAL METHODS

The cereals were grown in duplicated 1/20-acre plats. The wheat was seeded about 2.5 inches deep and there was sufficient moisture to start the crop without irrigation. The plats were given a 3 to 4 inch irrigation every 2 weeks, or a total of 18 inches, beginning about June 5 and ending about August 5. A double disc drill was used which spaced the rows 7 inches apart. The grain was harvested with a binder and threshed from the shock.

Counts were made of the number of plants in a 3-foot section of a single drill row in two places on each plat after emergence and before the crop tillered. If a count appeared not to be representative, as occasionally happened, another adjacent 3-foot section of the same row was included and the number of plants recorded for the 6 feet. After the grain matured counts were made of the number of heads on a similiar area in each plat. In the heavier rates of seeding there were a few small heads with short straw and few kernels which were not included in the counts.

Rates of seeding as shown in the tables indicate amounts which the drill was set to seed rather than exact quantities. In seeding increase fields the drill seeded very close to the rates indicated.

RESULTS WITH WHEAT

Federation wheat was seeded at four rates in 1932 to 1935. Table 1 shows the rate of seeding in pounds per acre, and the annual and average number of plants and heads per lineal foot in the drill rows. The 33-pound rate gave 4 to 5 plants to the foot which averaged more than four heads per plant. The highest rate of seeding, 129 pounds per acre, resulted in 15.9 plants per foot and slightly more tha than 1.5 heads per plant. In 1934, under especially good conditions, the heaviest rate of seeding, 129 pounds per acre, produced 2.5 heads per plant. The same year 33 pounds of seed per acre produced 6.7 heads per plant. The data in Table 1 and Fig. 1 show that 33 pounds of seed produced 61% as many heads per foot as 129 pounds of seed, a rate four times as high.

Table 2 gives the annual and average yields of grain and straw per acre. The table and the graph in Fig. 1 show that the plants resulting from the light rates of seeding not only tillered more, but had more productive heads than the ones from the heavier rates. The 96 pounds of seed gave the best average yield of both grain and straw. The graph shows that a rate of seeding of 61 to 129 pounds per acre resulted in a fairly uniform average yield of both grain and straw. The 33-pound rate made distinctly lower yields. The tendency for the thinner stands to tiller more and produce more grain per head is also indicated by the presence of several small heads bearing little or no grain in the heavier rates of seeding.

In the plats seeded at the lighter rates there were numerous pigweeds, (*Chenopodium album*). Rates of 33 and 61 pounds of seed per acre were not sufficient to control the weeds.

TABLE 1.—*Annual and average number of plants and heads per lineal foot of Federation wheat under irrigation in the rate of seeding experiment at the Harney Branch Experiment Station, Burns, Oregon, for the years 1932–35, inclusive.*

Rate of seeding, pounds per acre	1932		1933		1934		1935		Average	
	Plants per lineal foot	Heads per lineal foot	Plants per lineal foot	Heads per lineal foot	Plants per lineal foot	Heads per lineal foot	Plants per lineal foot	Heads per lineal foot	Plants per lineal foot	Heads per lineal foot
33	4.9	14.0	4.1	17.3	4.4	29.6	4.0	14.3	4.3	18.8
61	8.4	14.3	7.6	19.5	9.2	36.7	6.3	18.4	7.9	22.2
96	13.4	13.5	10.1	24.9	13.3	40.2	9.3	18.7	11.5	24.3
129	17.6	13.6	13.4	25.4	17.7	44.4	14.7	18.7	15.9	25.5

TABLE 2.—*Annual and average yields of grain and straw per acre of Federation wheat in the rate of seeding experiment at the Harney Branch Experiment Station, Burns, Oregon, for the years 1932–35, inclusive.*

Rate of seeding, pounds per acre	1932 Yield per acre		1933 Yield per acre		1934 Yield per acre		1935 Yield per acre		Average Yield per acre	
	Bushels of grain	Tons of straw	Bushels of grain	Tons of straw	Bushels of grain	Tons of straw	Bushels of grain	Tons of straw	Bushels of grain	Tons of straw
33	38.9	1.06	29.0	1.71	92.2	3.08	47.2	1.74	51.8	1.90
61	43.5	1.12	37.7	2.16	94.0	3.48	48.0	1.49	55.8	2.06
96	48.2	1.33	50.3	2.20	95.3	3.14	44.8	1.65	59.7	2.08
129	32.9	.99	40.8	2.38	98.8	3.68	47.3	1.43	55.0	2.12

Baart wheat was also grown in 1932 in the rate of seeding experiment and seeded at the same rates as Federation. Fewer plants resulted per foot due to size of seed. With Baart there was the same general tendency for the low rates of seeding to tiller and produce enough more grain per head to yield as well as the heavier rates of seeding. The average yield of Baart was about 80% that of Federation.

RESULTS WITH OTHER CEREALS

Trebi and O.A C. No. 7 barley were each grown 2 years in the experiment. They were seeded at the rates of 44 to 116 pounds per acre. The lower rates of seeding produced plants which tillered more so that there was very little difference in the number of heads per lineal foot at harvest time from the various rates of seeding. The medium and heavier rates of seeding yielded 5 to 10% more grain than the 44-pound rate of seeding. Less than 80 pounds per acre of seed did not hold weeds in check.

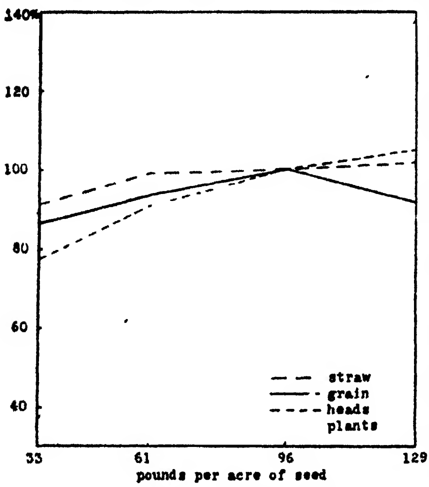

FIG. 1.—Four-year average yield of Federation wheat in percentage of the 96-pound rate of seeding.

Markton oats were sown at nine rates in 1933. They were seeded at rates of 44 to 135 pounds per acre. The grain used had a test weight of about 40 pounds per bushel. Rates of 45 to 50 pounds per acre resulted in the lowest yields. Rates of 58 to 105 pounds showed little variation in yield per acre. The lower rates tended to make up for the lack of plants by tillering and by better developed panicles. Small unfilled heads in all plats, especially in the heavier rates of seeding, were more abundant in the oats than in the other cereals. There were very few weeds in any of the plats of oats.

Beardless spring rye was seeded at eight rates ranging from 33 to 113 pounds per acre in 1932. More plants and heads per lineal foot resulted from the seeding of rye than from any of the other cereals. The rye also tillered more than the other grans. The 33-pound rate averaged 5.5 heads per plant and the 113-pound seeding 2.5 heads per plant. However, a fairly uniform yield of both grain and straw resulted. There was a considerable amount of weed seed in the soil, but all the rates of seeding of rye controlled the weeds satisfactorily.

Contrary to what might be expected, the length of straw of the lighter rates of seeding was not generally more than of the heavier rates. The height of plants was about the same each year for each rate of seeding with all the cereals.

SUMMARY AND CONCLUSIONS

Results are reported of a rate of seeding experiment with cereals grown under irrigation at an altitude of 4,139 feet, where frosts are frequent in the early part of the growing season and where there is a relatively large amount of sunshine and low relative humidity.

Four years' results with Federation wheat seeded at 33 to 129 pounds per acre resulted in more than 4 heads per plant from the lightest rate of seeding and a gradual decrease in heads per plant to about 1.5 from the heaviest seeding. Thinner stands produced not only more heads per plant but also more grain per head than the thicker stands. A rate of seeding of 61 to 129 pounds per acre resulted in a fairly uniform average yield of both grain and straw. The optimum rate was 96 pounds. Less than 96 pounds of seed per acre was not sufficient to control weeds on foul land.

One year's results with Baart wheat showed similar trends but gave a lower average yield than Federation.

Two years' data with Trebi and O. A. C. No. 7 barley resulted in about the same number of heads per lineal foot for rates of seeding of 44 to 116 pounds per acre and only the 44-pound rate yielded decidedly lower than the higher rates of seeding.

One year's results with Markton oats gave similar yields for rates of 58 to 135 pounds per acre and inferior yields for 45 and 50 pound rates.

Beardless spring rye seeded at eight rates of 33 to 113 pounds per acre gave a fairly uniform average yield for all rates. More plants per lineal foot and more heads per plant resulted from rye than from any of the other cereals.

The cereals show remarkable ability to adjust themselves to environment through tillering. The results show that very low rates of seeding tend to be compensated for by increased tillering.

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THE STIMULATION OF ROOT FORMATION ON ALFALFA CUTTINGS[1]

GLENN W. BURTON[2]

THE work of Zimmerman and Wilcoxon[3] with various organic chemicals which stimulated root development upon the stems of growing plants suggested the use of these chemicals to aid in the vegetative propagation of outstanding alfalfa plants obtained in the breeding nursery. Not only might a much greater quantity of seed be obtained in this way, a very important consideration in breeding work, but also the establishment of a number of individuals of the best plants in the greenhouse for seed production without disturbing the originals in the field would be possible, affording an opportunity to make additional observations on the adaptability of such plants in the field.

In the spring of 1936 three preliminary experiments were conducted on 270 cuttings taken from a number of different alfalfa plants. The treatment consisted of cutting alfalfa stems into two-node lengths, stripping off the leaves from the lower node, and placing the cutting in a water solution of the organic chemical for a period of 5 to 10 minutes. Indole acetic acid was used at a concentration of 50 p.p.m. Since alpha-naphthalene acetic acid could not be purchased for this study, an effort was made to synthesize the compound by refluxing naphthalene and chloracetic acid in equivalent proportions at 175°C for a period of 72 hours. The resultant organic residue was then treated with 10% sodium hydroxide, the filtrate with 10% hydrochloric acid, and the precipitate further purified with hot water. The slightly milky solution obtained in this manner was used as the stimulating substance. It was recognized that, while the above procedure should yield largely the alpha form of naphthalene acetic acid, some of the beta form might also be present. The yield was too low to permit the determination of the purity of the product used.

After treatment, the cuttings were placed in flats of sterile sand, where they were watered and covered with glass to prevent excessive transpiration.

The above studies led to the following conclusions:

1. Naphthalene acetic acid, as Zimmerman and Wilcoxon found on stems of growing plants, was superior to indole acetic acid in stimulating the formation of adventitious roots from cuttings.

2. Both compounds tested caused more roots to be formed per cutting and stimulated slightly earlier formation of these adventitious roots than when the cuttings were untreated.

3. Although in several instances a greater percentage of the treated cuttings formed roots than the untreated cuttings, the results indicated that this was not always true.

[1]Contribution from the Agronomy Department, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Approved by the Director as Journal Series Paper. Received for publication July 9, 1936.

[2]Agent, U. S. Dept. of Agriculture, Tifton, Ga.; formerly Research Assistant at the New Jersey Agricultural Experiment Station.

[3]ZIMMERMAN, P. W., and WILCOXON, F. Root stimulation and induction of adventitious roots. Contr. Boyce Thompson Inst., No. 3, July-Sept. 1935.

4. Cuttings from the tip of the alfalfa stems formed longer adventitious roots than cuttings farther down the stem in both treated and untreated lots. Such tip cuttings also rooted more frequently than lower cuttings of both treated and untreated stems.

5. A preliminary determination of the proper concentration of the stimulating substances and of the length of the period of treatment was found quite essential, since injury resulted in several instances of over treatment.

6. That varietal differences in response to treatment do occur is demonstrated in Fig. 1.

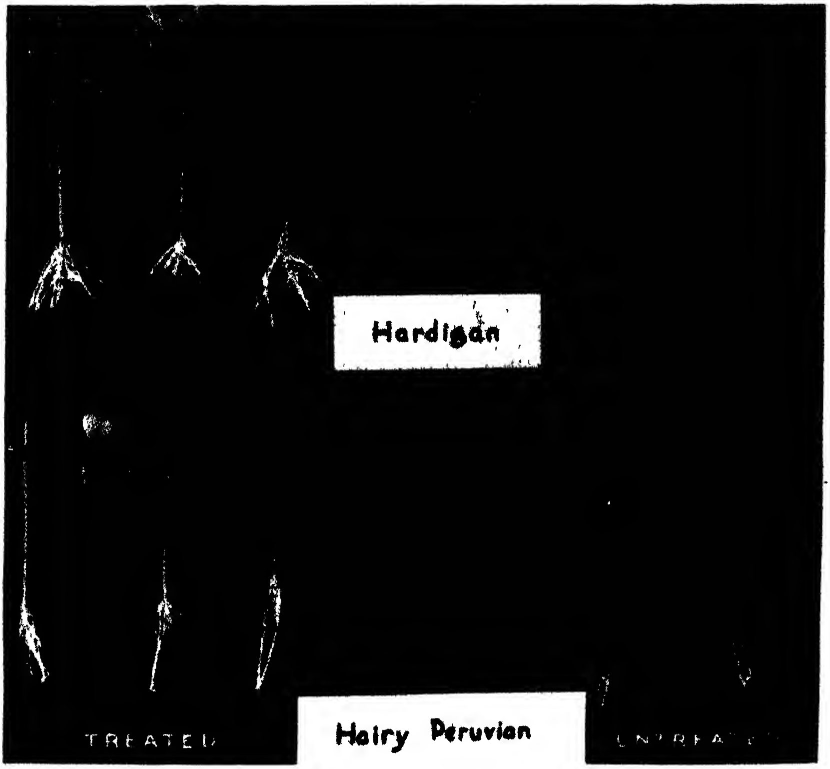

FIG. 1.—Differential response of alfalfa variety cuttings to no treatment and to a 5-minute treatment in a water solution of naphthalene acetic acid.

7. The greater abundance of adventitious roots and their more nearly horizontal position on Hardigan as compared with Hairy Peruvian cuttings suggest that the abundance and angle of adventitious roots so formed may be in close correlation with the abundance and angle of branch roots on the parent plant. Hardigan has a well-branched root system with the branches assuming angles similar to those in the cuttings illustrated above, while Hairy Peruvian has a distinct tap root with its few branches assuming a more nearly perpendicular position.

VARIATIONS IN YIELD OF PURE LINE GREEN MOUNTAIN POTATOES GROWN IN A CONTROLLED ENVIRONMENT[1]

O. BUTLER[2]

IT is commonly believed that selection does increase the yield of potatoes and that certain pure lines of a healthy stock are more productive than others, and field data are not lacking illustrating the benefits that accrue from selection. It would seem, therefore, that if one pure line of potato had inherently greater yielding capacity than another pure line of the same variety that this characteristic would be maintained unimpaired in succeeding generations were care taken to eliminate, in so far as possible, variations induced by the milieu.

An attempt has been made to submit this view to experimental verification in the case of the Green Mountain potato. Ten tubers between 50 and 70 grams in weight, selected at random from the seed plat bin of a certified seed grower, were bisected along the major axis, trimmed to weigh between 20 to 25 grams and planted in large pots containing equal amounts of air-dry soil carefully and thoroughly mixed to insure uniformity. Water was added to each pot in amount equal to 60% of saturation of the air-dry soil. The saturation point of the soil was determined for each pot separately, and all pots used in any one experiment at the working percentage of water used came within the maximum range of 4%.

One set of half tubers were grown at a mean temperature that varied slightly from year to year but lay within the limits 12.9° and 15.47°C. The other set of half tubers were grown at mean temperatures that ranged between 19.92° and 21.7°C. For convenience, we will speak of the former as being grown at 15°C and the latter at 20°C.

The plants were grown for approximately the same length of time each year timing from date of emergence to date of harvest. The seed was planted at the end of January or early in February, and the crops were harvested at the end of April or in May.

A number of experimental cultures have been grown under the same environment, or under conditions involving a change in environment from one generation to the next, for three or more generations, but since the data obtained are mutually supporting, it would be redundant to attempt to present it in full. We will present simply the data for those experiments which are most extensive and illustrate most fully the pertinent facts.

EXPERIMENTAL

YIELD INHERITANCE IN TUBER UNIT CULTURES

The data presented in Table 1 show the variations in yield met with over a period of three generations of the progeny of 10 tuber

[1]Contribution from the Department of Botany, New Hampshire Agricultural Experiment Station, Durham, N. H. Received for publication July 16, 1936.

[2]Botanist.

units grown at mean temperatures of 15°C and 20°C, respectively. A glance at the table shows that in the case of the first generation plants grown at 15°C there was a difference in yield between the most productive and least productive unit of 37.7%, but that in the case of the plants grown at 20°C the difference was only 14%. It will also be noted that the highest yielding unit in the series grown at 15°C was not the same as in the series grown at 20°C and that the lowest yielding units in both series were not of the same origin. Furthermore, no two plants occupy the same position in both series of cultures. Considering now the behavior of the plants of the second and third generations we will note in the first place that the difference in yield between the most and least productive units was 20.4% in the second generation and 8.7% in the third generation, whereas in the cultures grown at 20°C the difference in yield between the most and least productive units varied but little from one generation to the next; 13% in the second, and 15.36% in the third.

TABLE I.—*Yields of tuber unit cultures of Green Mountain potatoes grown for three generations at 15°C and 20°C, respectively.*

Seed piece taken from	1st generation		2nd generation		3rd generation	
	Yield, grams	Rank	Yield, grams	Rank	Yield, grams	Rank
			Plants Grown at 15°C			
H 6	572.0	1	513.0	8	391.0	2
H 7	552 0	2	611.0	3	381.0	4
H 5	538.0	3	616.0	2	396.0	1
H 10	537.0	4	611.0	3a	376.0	5
H 4	533.0	5	568.5	5	387.0	3
H 1	524.0	6	557.0	6	——	-
H 8	520.0	7	569.5	4	370.0	7
H 9	520.0	7a	569.5	4a	357.0	9
H 2	515.0	8	552.0	7	372.0	6
H 3	356.0	9	645.0	1	366.0	8
			Plants Grown at 20°C			
H 7	513.0	1	434.5	5	345.0	2
H 9	507.0	2	489.0	3	313.0	6
H 1	502.0	3	490.5	2	298.0	8
H 8	499.0	4	461.0	4	292.0	9
H 5	497.0	5	420.0	7	315.0	5
H 2	490.0	6	525.0	1	357.0	1
H 3	488.0	7	378.0	9	344.0	3
H 10	481.0	8	431.0	6	334.0	4
H 6	480.0	9	403.0	8	301.0	7
H 4	441.0	10	374.5	10	——	-

In the cultures grown at 15°C the unit producing the highest yield in the first generation yielded the least in the second and was second highest in the third, while the least productive unit in the first generation was the most productive in the second and penultimate in the third.

In the cultures grown at 20°C the most productive unit in the first generation occupied fifth position in the second and second position in the third.

In another experiment in which three generations of plants have been grown, plants from tubers of the same origin planted at 15°C and 20°C, respectively, behaved much like those in the first series, except that the yield differences between the most productive and least productive units in the cultures at 15°C did not grow less from generation to generation and in the cultures at 20°C showed wide fluctuations from one year to the next not evident in the first series.

To summarize briefly, the following results were obtained: In the cultures grown at 15°C, the unit producing the highest yield during the first generation gave the lowest yield during the second and the highest again during the third. The lowest yielding unit during the first generation occupied second position during the second and third position in the third. The yield differences between the highest and lowest producers were 41.6% in the first generation, 12.9% in the second and 22.7% in the third.

In the cultures grown at 20°C, the unit giving the highest yield in the first generation also occupied first position in the second and third generations. The lowest yielding unit in the first generation was next to the lowest in the second and lowest in the third. The lowest yielding unit produced 46.2% less than the highest in the first generation, 17.6% less in the second, and 24.8% less in the third.

In the series grown at 15° and 20° C, the highest yielding units in the first and third generations were of the same origin, while in the second generation the highest yielding units were of different origin. The lowest yielding units in the first and second generations were of different origin but of the same origin in the third generation.

Data have also been obtained in the case of one series of cultures of five separate units grown at 20°C covering six generations and for four of these units covering seven generations. In the first generation, the lowest yielding unit produced 4.8% less than the highest, in the second generation 22.7% less, in the third 15.3%, in the fifth 44.9%, and in the sixth 35.1% less. No yields were obtained for the fourth generation as the soil in which the plants were grown proved toxic and they had to be transferred to beds to save them.

In Table 2 is given the position in order of productiveness of the units at each generation, number one being the most productive unit and number five the least in each case.

TABLE 2.—*Yields of tuber unit cultures grown for six and seven generations at 20°C.*

Reference number of unit	Position in scale of productiveness occupied at different generations						
	First	Second	Third	Fourth	Fifth	Sixth	Seventh
H7	1	3	1	–	3	1	–
H9	2	1	4	–	1	5	3
H8	3	2	5	–	4	3	4
H5	4	4	3	–	5	4	1
H3	5	5	2	–	2	2	2

The data presented in the table show that the position of the several units in the scale of productiveness varied from year to year and that unit H5 in particular, which generally occupied a low position in the scale for the first six generations, was the highest yielder in the seventh generation.

VARIATIONS IN YIELD BETWEEN TUBERS OF THE SAME UNIT

The variations in yield that we have found to occur in pure-line cultures of different origin are repeated when a study is made of the behavior of successive generations of plants grown from tubers of the same hill unit. Two tubers were selected from each of three hill units and three generations of plants grown from them. The data presented in Table 3 show that in the first generation the difference in yield between the plants from the two H9 tubers was 53.8% in the cultures grown at 15°C and 26.8% in those grown at 20°C. In the case of the plants from the two H5 tubers, on the other hand, the yields of the plants grown at 15°C differed by 2.4% and those grown at 20°C by 28.9%, a complete reversal of form, while the plants from the H3 tubers behaved like those from H5, though the differences between the two cultures were less marked.

It will also be noticed that in the first and succeeding generations the capacity to yield of the cultures issued from the same tuber and grown at 15°C and 20°C, respectively, was the same only in the case of the units issued from H9.

Obviously, plants originating from tubers from the same hill show as large variations in yield as plants derived from tuber units selected at random.

TABLE 3.—*Yield of tubers from the same hill and of the progeny derived from them.*

Origin and number of seed piece		First generation, grams	Second generation, grams	Third generation, grams
Plants Grown at 15°C				
H9	Tuber a 1st half	119.0	309.0	205.0
	Tuber b 1st half	258.0	231.0	211.0
H5	Tuber a 1st half	160.0	272.0	197.0
	Tuber b 1st half	164.0	308.0	205.0
H3	Tuber a 1st half	133.0	333.0	213.0
	Tuber b 1st half	128.0	348.0	207.0
Plants Grown at 20°C				
H9	Tuber a 2nd half	101.0	205.0	230.0
	Tuber b 2nd half	138.0	197.0	254.0
H5	Tuber a 2nd half	107.0	309.0	270.0
	Tuber b 2nd half	76.0	255.0	298.0
H3	Tuber a 2nd half	95.0	242.0	238.0
	Tuber b 2nd half	107.0	273.0	272.0

TUBER SET AND YIELD

In the 10-tuber unit cultures grown in experiment 1 for a period of three generations at 15°C and 20°C, respectively, data were taken on number of tubers produced per hill above 15 grams in weight. It was found that, while in general, no relation between tuber set and yield obtained, plants producing only five tubers never gave the highest yield, but neither were they always and invariably the least productive, and plants setting 10 tubers never produced the lowest yield, but neither were they consistently more productive than hills with 6, 7, 8, or 9 tubers.

No evidence was obtained that tuber set is inherited since no relationship was found to exist between the number of tubers produced by the several units in the first generation with the number produced in successive generations. Of the cultures grown at 15°C, seven units in the second generation produced more tubers per plant than in the first generation, two produced the same number, and one was less productive. In the third generation, one unit produced the same number of tubers as in the second generation, two units set more tubers, but in the remaining units fewer tubers were formed. The units in the cultures grown at 20°C also showed variations from generation to generation.

CONCLUSIONS

The conclusion to be drawn from the facts presented here would seem to be inescapable. To select seed from healthy stock on the basis of yield and tuber number is labor lost. All that is necessary to maintain productivity is to select from healthy hills of uniformly vigorous plants.

THE EFFECT OF LATENT INFECTION ON THE SMUT-RESISTANT MARKTON OAT[1]

HARLAND STEVENS[2]

THE question has arisen, Is there a crop variety so resistant to a disease that no injury whatever will result from its contact with the causal organism under conditions normally favorable to infection? The Markton oat, from all outward or visible appearances, is highly resistant to the smuts found in the United States. A study was begun on the effects of systemic smut infection in Markton grown on irrigated land. Idamine, a variety very susceptible to the smuts of oats, was grown as a control.

Bayles and Coffman[3] first found some evidence of injury in a resistant variety when grown from inoculated seed. Hubbard and Stanton[4] have shown that under dry-land conditions at Mandan, N. D., smut-resistant varieties grown from inoculated seed were adversely affected regardless of the absence of smut sporulation in the panicles. The present investigation was started by Loren L. Davis at the Aberdeen Substation, Aberdeen, Idaho, in 1930. It was continued by the writer in 1932, 1933, and 1934.

When the smuts are present as mycelium in the culms of oat plants without external manifestation or sporulation in the panicle, it is known as "latent" infection.

METHODS

Three seed treatments were used, *viz.*, (1) no inoculation with smut spores or other treatment; (2) no inoculation with smut spores and treated with a solution of 1 pint of formaldehyde (standard formaldehyde, 37% formalin) to 40 gallons of water; and (3) inoculation with smut spores, hulled (dehulled) seed being used exclusively.

Inoculation for treatment 3 was accomplished by applying a small portion of inoculum to seed in the coin envelopes in which it had been prepared for seeding. The inoculum was applied just before seeding and the envelopes were shaken vigorously to blacken all seeds thoroughly with smut spores. Covered smut, *Ustilago levis* (Kell. and Sw.) Magn., with some slight contamination of loose smut, *U. avenae* (Pers.) Jens., was used in this experiment.

Each year 500 seeds for each treatment and each variety were sown. Each seed was spaced 3 inches apart in 5-foot rows and the rows spaced 1 foot apart. The seed was sown in soil containing sufficient moisture to insure germination of the seed and growth of seedlings until first irrigation.

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[1]Results of cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept of Agriculture, and the Idaho Agricultural Experiment Station, Moscow, Idaho. Received for publication July 16, 1936.

[2]Assistant Agronomist, Division of Cereal Crops and Diseases.

[3]BAYLES, B. B., and COFFMAN, F. A. Effects of dehulling seed and of date of seeding on germination and smut infection in oats. Jour. Amer. Soc. Agron., 21: 41–51. 1929.

[4]HUBBARD, V. C., and STANTON, T. R. Influence of smut infection on plant vigor and other characters in smut-resistant oat varieties. Jour. Agr. Res., 49:903–908. 1934.

TABLE 1.—*Effect of smut infection on number of plants, yield of grain per row, and yield of grain per plant in Markton and Idamine oats grown at the Aberdeen Substation, Aberdeen, Idaho, 1932–34.*

Seed treatment	Average number of plants per row				Yield of grain per row, grams				Yield of grain per plant, grams			
	1932	1933	1934	3-yr. av.	1932	1933	1934	3-yr. av.	1932	1933	1934	3-yr. av.
					Markton							
1, Not smutted and not treated	15.1	15.0	11.2	13.8	247.7	403.7	214.5	288.7	16.5	26.9	19.2	20.8
2, Not smutted and treated with formaldehyde	12.8	8.8	7.6	9.7	243.3	234.8	128.0	202.1	19.1	26.8	16.8	20.9
3, Smutted and not treated	10.5	10.8	5.7	9.0	193.5	337.1	116.1	215.6	18.5	31.2	20.5	23.4
					Idamine							
1, Not smutted and not treated	15.2	13.5	12.4	13.7	189.9	280.4	200.9	223.7	12.5	20.7	16.2	16.5
2, Not smutted and treated with formaldehyde	10.7	8.2	9.7	9.5	159.9	197.5	126.3	161.2	15.0	24.0	13.1	17.4
3. Smutted and not treated	8.4	12.5	1.5	7.5	40.4	66.9	17.3	41.5	4.8	5.4	10.9	7.0

EXPERIMENTAL RESULTS

A summary of results is presented in Table 1. Data are given on the number of plants per row, yield of grain per row, and yield of grain per plant for each treatment for each of the two varieties.

In the susceptible as well as in the resistant variety, treating the hulled seed with formaldehyde decreased the number of plants per row but not so much as did inoculating it with smut spores. The yield of grain per row was decreased in both varieties and in the resistant variety the yield per plant was increased. This latter result apparently was due to the thin spacing caused by poor germination. In the susceptible variety, according to the data of Table 1, treatment 3 greatly reduced the yield of grain per row and also the yield of grain per plant. This is because of the great number of plants that had all or part of the kernels smutted.

No significant variation in plant vigor resulting from the seed treatments was observed in the resistant variety. The thinner spacings yielded on an average slightly more grain per plant. In general, these results substantiate those obtained by other workers in that resistant varieties are adversely affected by the smut organism.

Several abnormalities were produced in the susceptible variety by smut infection. Many of the panicles of Idamine were smaller and of various forms; however, the production of a high percentage of the so-called "false node" in Idamine was the most striking. Normally, the "false node" is not a varietal character of Idamine, Silvermine, or closely related strains.

SUMMARY

The smut-resistant Markton oat variety is injured by inoculation and infection with smut that results in the killing of many seeds and thus reduces the stands. After the plants emerge and become established, however, there appear to be no detrimental effects.

Under normal field practice smut would not be a factor in a resistant variety because practically no inoculum would be produced to inoculate and infect the following crop naturally.

THE POINT-OBSERVATION-PLOT (SQUARE-FOOT DENSITY) METHOD OF VEGETATION SURVEY[1]

GEORGE STEWART AND S. S. HUTCHINGS[2]

FOR years ecological and range studies have been impeded by the need for a more accurate and time-saving method of making an inventory of plant cover on a given area. At a range-management conference in 1927, 40 to 50 range administrators and researchers attempted to estimate vegetation by the large-plot method. Independent estimates of vegetation in the same plot by experienced range men showed considerable variation, and, as a whole, seemed high. In 1930, the senior author began to devise a method of inventorying the plant cover that was aimed to correct the weaknesses of the methods then in use.

This paper explains the working of the new point-observation-plot method of vegetation survey which has evolved over a period of 4 years. The following formal description is deemed necessary because this method is already highly useful and has been tried sufficiently by many agencies concerned with the measurement of range plant growth to show its practicability. Its application extends throughout the fields of range management, pasture management, agronomy, and soil erosion. It provides definitely quantitative data instead of merely qualitative.

The new method is founded on the technic long used by plant breeders to obtain reliable preliminary field tests of large numbers of strains. It includes randomization and replication of plots and, therefore, lends itself readily to statistical analysis. In addition, it has been modified to include some phases of the timber survey and certain refinements of the range reconnaissance survey long used by the Forest Service and other organizations. The junior author, who has had considerable experience in range reconnaissance, was instrumental in adapting certain principles of this work to the new method.

NEED FOR A NEW METHOD

The point-observation-plot method, as the name indicates, utilizes a series of replicated plots from which is recorded the kind and amount of vegetation on a small area at a particular point. The charted quadrat, in a way, furnishes these data, but this method is too time-consuming to be used widely for surveys. Also, the meter quadrat, sometimes used in the area list method, is often too small to

[1]Contribution from the Intermountain Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture, Ogden, Utah. Received for publication July 27, 1936.

[2]Senior and Assistant Forest Ecologists, respectively. Acknowledgments are gratefully made to G. D. Pickford and J. F. Pechanec of the Intermountain Forest and Range Experiment Station for help in developing and in testing the point-observation-plot method; to Dr. W. P. Cottam of the University of Utah for testing it; and to Director R. E. McArdle and Dr. D. F. Costello of the Rocky Mountain Forest and Range Experiment Station for introducing this method widely in their region, both to officials of the Forest Service and to those of other agencies.

contain the 20 to 50 or more individual plants of major species which must be included to overcome the differences of individual plants. The large-estimate-plot method, in part, compensates for drawbacks encountered in the use of the quadrat, but both lack elasticity and speed.

In both the quadrat and the large-estimate-plot methods, the areas to be studied are ordinarily "selected" because of the slow process of taking data. This practice prevents randomization and replication. On the other hand, the point-observation-plot method provides for randomization and replication, insures a closer scrutiny of the plant cover than is the case on the large-estimate plot, a greater ease and reduction of error in compilation, and an immense saving in time.

THE PLOT

In size, the plot commonly used in the new method is usually 100 square feet in area, though on sparse desert vegetation often it has seemed best to use 200 square feet. The size may vary within reasonable limits, as it needs only to be large enough to be representative of the major forage species, small enough to be viewed readily from above, and to require only a few minutes to observe and record the data. In all plant associations so far studied, except in the desert shrub, a plot area of 100 square feet has proved most satisfactory.

For convenience and speed, the circular plot, so far used in tests with the new method, has many advantages. Following is the method used in measuring off a plot to be studied: Since the radius of a 100 square-foot circle is 5.64 feet, a light chain of that length or a strong string, without stretch, is used to fasten two pegs together which are used to describe the desired circle. One peg is driven in the ground to serve as a pivot about which the other turns in tracing the circumference. Sometimes a straight piece of wood or light metal with a peg at the end is used for this purpose; or, in taller or brushy vegetation, surveyor pins, pegs, or other easily visible reliable markers are sometimes used. The error incurred in designating the plot is small when reasonable care is exercised in the operation.

THE ESTIMATE

Previous to beginning the inventory, a decision is reached as to the classes of vegetation for which data are to be recorded. For some purposes, all grasses may be considered as one group, all range weeds another, and all shrubs another. Usually, owing to differences in palatability, the more abundant species of each plant class will be listed separately. This may be done to whatever degree of refinement is desired, i.e., there may be as few or as many groups according to the information desired and as the time available may warrant. This decision requires careful thought lest the surveyor overburden himself with too many details.

With these groups or species in mind, the estimator visualizes how much current growth of a given vegetation group equals 1 square foot of plant cover. This done, he counts up the number of square feet

of plant cover of that species or plant group and records it on an especially prepared form. He then makes the estimate for other species or plant groups and records the data. Usually, it is sufficiently accurate to record the ground cover of each species or group to the nearest 1/4 square foot. The scarcer species may have only a small volume on one plot, too little to equal 1/4 square foot. This condition is indicated by a "trace" (T) unless it is not desired to record such information. The estimate of fractions of a square foot of ground cover has limits. For example, ¼ square foot is the middle point between ⅛ and ⅜, ½ square foot between ⅜ and ⅝, ¾ square foot between ⅝ and ⅞, and 1 square foot between ⅞ and 1⅛. The ½ square foot may be the smallest fractional area of plant cover needed on an extensive survey, in which case the limits are ¼ square foot below and ¼ above each figure to be recorded. Sometimes for very careful work it may be desirable to take data to ⅛ square foot, making the limits $\frac{1}{16}$ and $\frac{3}{16}$ square foot, etc.

PLOT SYSTEM AND REPLICATION

When the data are taken on one plot, the estimator moves in a predetermined direction by a distance interval also prearranged. Whether the interval is 100 feet, 0.1 mile, or 0.5 mile, depends on the intensity of the survey, inasmuch as the method is adjustable to any intensity desired. When the interval has been measured or paced according to the working plan, the point at the end of the interval mechanically becomes the center of the next plot, and the circumference of the plot is drawn in as previously described. In order to provide for randomization and replication, data are gathered from a large number of plots spaced at mechanical intervals.

For example, to compare the amount of plant growth on a protected range with that on a heavily grazed one, the worker estimates the particular vegetation in which he is interested on 10, 20, 30, 50, or 100 plots on each area and compares the number of square feet of this kind of vegetation found on each plot of the two series studied. Often the area of the protected or moderately used range is smaller than that of the heavily used one. This condition is of little consequence if care be taken to compare only that part of the heavily used range which is truly comparable with the "protected" area, i.e., comparisons should be made between areas on which the vegetation would have been essentially equal under equal treatment.

COMPARISON MUST BE RELIABLE

True comparability is highly important in making plant depletion inventories, because wide variations in productivity have always existed on different areas on the original undisturbed range. Comparisons must, therefore, be real and not specious. Minor differences will occur on any areas, but consequential ones can and must be eliminated or the comparisons are of little value; therefore, great care has been taken in this respect in the inventories made by the Intermountain Forest and Range Experiment Station.

Frequently a fence marks the boundary between a moderately used and a heavily used range. An examination will usually reveal whether the range areas on the two sides of the fence have the same kind of vegetation, have comparable soil and moisture conditions, and are essentially equal in other respects. A series of plots in a line on one side of the fence is paralleled by a similar series on the other side. The two series are both far enough from the fence to omit the zone of animal concentration that almost invariably occurs along a fence. This is ordinarily not more than 40 to 100 feet, usually less. The mechanical interval between plots is the same on both "transects", as such lines of plots are designated.

At the Intermountain Forest and Range Experiment Station, two systems have been used in laying out the position of plots, (1) one for obtaining a comparison of forage on various range units; and (2), more important, one for setting up a network of plots over a given range to obtain a forage inventory, or to determine the volume of plant cover on a pasture or on a watershed. This second system is also used for establishing permanent plots from which data are to be taken in later years. However, since the first-named phase of this plot system, that of making comparative surveys, is the one so far used outside the Intermountain region, it is described first.

COMPARATIVE SURVEYS AND TYPE MAPS

Forage inventories made in 1932 and 1933 with the new method extended into approximately 80 typical range areas in Idaho, Nevada, Utah, and southwestern Wyoming. They afforded the only approximately accurate method of estimating the condition of range vegetation which has, since settlement, developed from uncontrolled grazing. In 1935 the Rocky Mountain Forest and Range Experiment Station adopted this plot system and further extended the survey into Colorado and Wyoming and into western Kansas and Nebraska. In 1936 the Forest Service, in cooperation with other agencies, plans to take many thousands of plot estimates. A survey of Utah ranges will be completed, as well as surveys in Idaho in some of the more important areas which were omitted in the 1932 study. The surveyor, by drawing in the type lines when he passes from one plant association to another, can, with little extra labor, also have, when the estimating is finished, a type map of the vegetation. The point-observation-plot method, as a new tool and because of the rapidity of its operation, has made such surveys possible.

COMPILING THE DATA

Since the original data are taken in square feet on plots of 100 square feet in area, they read in percentages directly without calculation or adjustment. Data-sheet forms (Fig. 1) are drawn up to accommodate 10 plots on one sheet, inasmuch as at least 10 plots are taken in one protected area or in one grazed area. When the number of plots taken exceeds 10, a multiple of 10 is used.

Clerks are able to compile the data quickly on adding machines and to mark off one decimal point to the left; whereas, the quadrat and large-estimate-plot methods require technicians to work through

SAMPLE PLOT - Transect

Location ENCLOSURE No 1 FREMONT COUNTY BURNING PROJECT
Transect No. # 1 Date JULY 2 1936 Examiner RALPH JENSEN
Type SAGEBRUSH GRASS

Plot Number	1	2	3	4	5	6	7	8	9	10	TOTAL DENSITY
Density	8 1/2	3 3/4	5 3/4	10 1/2	8 3/4	8 1/2	6 1/2	14 1/2	6 3/4	9	82 1/2
Species											
GRASSES											
Agropyron dasystachyum	1/2		1/4	3/4	1/4	1 1/2	3/4	1	1/2	1/2	6 1/4
Danthonia unispicata		1/4									1/4
Festuca idahoensis			1/4	1 1/4	1/4		1/4	1/4	1/2		2 3/4
Koeleria cristata										1/4	1/4
Poa secunda		1/2	3/4			1/2	1/4				2
Poa nevedensis				1/4		1/4		1/4	1/4	1/4	1 1/4
Stipa columbiana			1/4	1 1/2	1/4	1/2	1/4	1 1/4	2 1/2	2	8 1/2
Stipa comata				3/4		1/2		1 3/4			3
GRASSLIKE PLANTS											
Carex douglasii				1/4			3/4		1/2	1/4	1 3/4
Carex filifolia				1/2					1/4		3/4
WEEDS											
Achillea lanulosa			1/4			1/4					1/2
Antennaria microthecum										1/4	1/4
Eriogonum heracleoides						1/2					1/2
Gutierrezia sarothrae		1/2									1/2
Polygonum douglasii				1/4				1/4			1/2
Sphaeralcea munroana		1/4									1/4
SHRUBS											
Artemesia tridentata	8 1/4	2	3 1/2	5 1/4	7 1/2	4	3 1/4	9 1/4	2 1/4	5	50 1/2
Leptodactylon pungens		1/4									1/4
Prushia tridentata					1/4	1/4	1 1/2	1/2		1/2	2 1/2
Symphoricarpus oreophilus			1/4								1/4

FIG. 1.—Data sheet used by the Intermountain Forest and Range Experiment Station in taking field data and in compiling data regarding range surveys made by the point-observation-plot method. The major species for which data are to be gathered are listed at the left. The number of square feet of each species is recorded in the correct narrow column. Each sheet holds data from 10 plots, which are averaged in the column at the extreme right. This column is then added to give the total mean density for 10 plots in this plant type. When data are taken from 20 or more plots, two or more sheets are used and these summarized on an additional sheet. All figures thus recorded are in percentages. Machine addition and pointing off of a decimal are all the calculations required.

an intricate system of cross-multiplications and divisions. The compiled figures for quadrats and large-estimate plots usually bear three to five decimal points, whereas frequently none and at most two decimal points are required in making computations with the point-observation-plot system. Thus, the chances of making errors are greatly reduced.

One simple mathematical addition and the pointing off of a decimal place keep the mean figure used much nearer to the observed data than is possible with the intricately "calculated" figures derived by the other methods. This use of nearly "real" figures is a scientific advantage not to be overlooked.

FORAGE INVENTORIES AND PERMANENT PLOTS

A second use of the point-observation-plot method is in making a forage inventory of an experimental range or pasture before it has been grazed or at intervals during grazing. On the Desert Experimental Range such a study was made by means of a network of 100 plots to the section, equidistant in cardinal directions. A survey was made of each of the 16 320-acre pastures by means of 128 plots in 16 lines of 8 plots each. A similar survey will be repeated each season.

Many hundreds of permanent plots have been established by this method at the Intermountain Station. Some are grouped in a network on comparative areas inside and outside of enclosures, others are in transect lines across a grazed zone, and still others radiate outward from watering places around which progressive forage depletion is thought to be taking place. When fortified with chart quadrats and brush plots,[3] a better picture of the kind, the growth, and the changes in vegetation can be obtained in a limited time by the point-observation-plot method than by any other yet described.

EROSION SURVEYS

Repeated observations by this new method at a large number of systematically located plots will also give a representative picture of surface soil erosion conditions, insofar as these can be determined on a small plot. Such a picture has been obtained very successfully on the Davis County flood area just north of Salt Lake City. Variance calculations established that the amount of vegetation on small plots is significantly related to erosion conditions of the surface soil. The point-observation-plot method, by providing replicated and randomized samples, is a valuable addition to the technic of conducting a survey of surface erosion.

METHOD EASY TO LEARN AND OPERATE

During more than 4 years in testing this method it has been demonstrated that several estimators can make approximately the same estimations for given plots, provided they practice together for 2 or 3 half-days and check with each other occasionally. It can also

[3] PICKFORD, G. D., and STEWART, GEO. Coordinate method of mapping low shrubs. Ecol., 16:257–261. 1935.

be determined, within narrow limits, whether the estimate is essentially correct. For this purpose, vegetation is cut below the surface of the ground with a knife, a sharpened shovel, or some other tool and moved gently together so as to cover the ground. The plants are not jammed together, but placed where small uncovered angles, when viewed from above, are compensated for by similar small angles where the leaves overlap. Thus the space occupied by each class or species can actually be measured. If this procedure is followed carefully once or twice a day for a few days, most men educated in plant science will soon be able to make estimates that are consistent with each other and that are close to the true value. Consistency and correctness result from the use of a small plot on which the estimator can look directly down at the vegetation. The possibility of testing the estimate against its true value also counts for consistency and correctness. The inherent error in this estimate can be ignored because it can be kept small if care is exercised.

Two examples will also bring out concretely the ease with which men trained in plant science, but entirely unacquainted with the point-observation-plot method, learned and applied it on an extensive scale.

1 A professor of botany, working as a temporary employee of the Intermountain Forest and Range Experiment Station, was shown one afternoon in 1933 how to operate the method. He made estimates alone during the next forenoon, and in the afternoon checked with the authors. He then took six above average CCC boys, coached them for 2 or 3 days, and then added six more to his crew. Repeated careful checks showed that only general supervision by the authors was required. Data were taken from more than 11,000 plots in about 3 months. During the following winter all of the data from these surveys were compiled, checked, and rechecked by 25 untrained CWA workers supervised by one technically trained man.

2. In July of 1935, when the method was in a late stage of development and somewhat simplified, an ecologist with a doctor's degree, also a temporary employee of the Intermountain Station, did his first field work on range studies. For about half of the month he helped in a range survey by the point-observation-plot method. In September he went to another region and conducted a range survey without further help, except for the Intermountain field-data forms and instructions for compilation. He supervised a number of trained Forest Service personnel, none of whom had ever used the method before, in taking, during September and October, data on more than 4,000 range plots. During October and early November, office help, with a minimum of technical supervision, compiled the data and summarized them to show the relative depletion of plant cover on national forests, on state and private lands, and on public domain.

The progress made by these two men is in part explained by their technical training and high ability. However, examples are on record of range men of junior grade who, in 2 half-days, learned the method and thereafter made successful surveys with only one or two checkings by experienced users.

SAVES TIME

After 2 weeks' experience, one technical man working alone can take data at the rate of 20 to 50 plots in a day, instead of at the rate of 2 to 6 chart quadrats a day for two men, or of 2 to 4 large-estimate plots a day for one man. Compilation, consisting of machine addition and one simple division, often the mere pointing off of a decimal, is also about 5 to 10 times as rapid as that for the other methods. This rapidity makes possible the taking of data from a large number of plots with the minimum of help.

MAKES POSSIBLE RANDOMIZATION AND REPLICATION

It is not the details of the plot or the system, important and useful as they are, that the authors regard as most valuable, however. It is the system of point observation, the randomized location of plots at mechanical intervals, and the full replication of plot data that makes it both biologically and statistically sound. Lack of randomization in the other methods prevents plots from being representative, and lack of full replication prevents them from being statistically reliable when used as units for a vegetation survey.

LENDS ITSELF TO STATISTICAL ANALYSIS

Numerical observations of several species of plants on a series of randomized and replicated plots, either with or without observations concerning erosion conditions, make possible statistical analyses of the data. Statistical studies can be made by the probable-error method, by analysis of variance, or by correlation coefficients, depending on the nature of the problem and the number and sort of numerical data. For example, Stewart and Keller[4] show that the point-observation-plot survey provides the ecologist with a means of making his observations definitely quantitative, instead of merely qualitative.

POSSIBLE VARIATIONS AND IMPROVEMENTS

Though a profound step in advance of systems used heretofore, the point-observation-plot method is not perfect. As yet, neither it nor the other methods have been so refined as to permit the proper adjustments for differences in height of plant growth which obviously influence the volume of forage produced. Two studies are in progress at the Intermountain Forest and Range Experiment Station in an effort to devise a suitable modification in the new method to allow for volume of forage. It is to be expected that other workers will develop improvements in the method, because the system by its very nature is highly adjustable.

CONCLUSIONS

After 4 years' trial over a wide territory, the following conclusions regarding the point-observation-plot method seem warranted:

[4]STEWART, GEO., and KELLER, WESLEY. A correlation method for ecology as exemplified by studies of native desert vegetation. Ecol., 17:—. 1936.

1. This method has proved superior to the chart quadrat and to the large-estimate-plot method of making comparative surveys of range vegetation. It should be given a trial in range reconnaissance.

2. It provides for randomization and replication of plots which make it a sound method, both biologically and statistically. In supplying soundness, and therefore, reliability, the new method provides a basis for a vegetation survey which does away with the necessity of "selecting" plots.

3. It is easy to learn and to operate. Its time-saving qualities so greatly reduce the labor cost of providing replication and randomization that these two essential requirements of a good survey and experimental grazing can be fully met. Forage inventories on both range and farm pastures can be made by the new method with a reasonable labor cost.

4. Surface soil erosion conditions can also be readily studied by using the point-observation-plot method. Replicated representative samples, made possible by this new method, will add much to the reliability of erosion surveys.

5. Data obtained by the method are subject to statistical analyses.

SUMMARY

1. A new plot method of vegetation survey, known as the point-observation-plot method, has been devised by ecologists of the Intermountain Forest and Range Experiment Station. This method has many distinct advantages over the ones formerly used. It has been nick-named the "square-foot-density" method because data are recorded in that unit.

2. The point-observation plot is usually 100 square feet in area, and for convenience is circular, though there is nothing essential in the shape of plot. The plot is marked off by drawing a circle around a central point which is located mechanically and in no way selected. Locating the plot mechanically without selection gives it randomness —an absolutely essential point in sampling an area.

3. One man can take data on from 20 to 50 plots in a day, thereby making possible full replication of observations -a second absolutely essential quality to statistically reliable data. Plots are replicated 10 or 20 (or other multiples of 10) times to afford representativeness and replication. Such replication may be in a line transect of plots or in a network of plots more or less equi-distant in one or more directions.

4. Separate workers can easily check with each other, i.e., one worker can duplicate another's data, if they practice together for a short time before beginning the survey.

5. Comparisons can be readily made of "protected" and heavily grazed areas, or of other range conditions.

6. The method is suitable for depletion surveys, for forage inventories, and for permanent plots; also for studies in range and pasture management, in erosion surveys, in agronomy, and in ecological observations.

7. Furthermore, it makes possible a statistical analysis of the data by probable errors, by analysis of variance, or by the correlation method.

RUBBER AS A PROTECTIVE DEVICE ON CONCAVE TEETH FOR THRESHING SEED BEANS[1]

B. L. WADE AND W. J. ZAUMEYER[2]

LOW germination of seed beans resulting from thresher injury to the seeds has received attention by investigators for some time Harter[3] found that thresher injury to the seeds was the cause of much of the "bald head" (an injury to the epicotyl) found in beans. Later, Borthwick[4] studied other types of injuries of baby lima beans due to the same cause. In a rather extensive study on this subject, Bainer and Borthwick[5] found a direct relation between cylinder speed of threshing machines and the percentage of seed damaged, the greater speed causing the larger amount of damage.

It has been claimed by some threshermen, seedsmen, and others that the use of rubber on the concave or cylinder teeth of threshing machines would greatly reduce the amount of cracking in seed beans. The investigations here reported were conducted to determine the extent to which damage is reduced by this means.

The beans used in 1934 were a mixture of miscellaneous F_5 and F_6 hybrid lots of the Stringless Green Refugee type. In 1935 the beans were from the F_3 generation of a hybrid of the Bountiful and Wells Red Kidney types. They were grown at Greeley, Colo., and were permitted to ripen completely on the plant in the field before threshing. The vines were pulled from the field in the morning and threshed in the afternoon of the same day. The vines and pods seemed drier this way than if pulled in the usual manner, when some greenness remained in the pods and then permitted to cure in small piles. It is known that beans cut a little too green are difficult to thresh because the pods dry tightly around the seeds, especially if the conditions for curing are unfavorable.

The Refugee type of beans used in 1934 would be considered by commercial threshermen as very difficult to thresh, while those used in 1935 were comparatively easier. In drying, the pods of the Stringless Green Refugee type adhere very closely to the seeds. In threshing, the pods frequently break crosswise at each side of the bean leaving it encased in a portion of the pod. The Bountiful types of beans split open along the sutures very easily when struck by the cylinder teeth, thus readily releasing the beans. For this reason such types of beans are less difficult to thresh than those of the Refugee type.

The thresher used was of a small Owen type consisting of two cylinders each 12 inches in diameter. They were 12 inches in length

[1]Contribution from the Division of Fruit and Vegetable Crops and Diseases, U. S. Dept. of Agriculture. Received for publication, June 19, 1936.

[2]Senior Geneticist and Associate Pathologist, respectively.

[3]HARTER, L. L. Thresher injury a cause of bald head in beans. Jour. Agr. Res., 40:371–384. 1930.

[4]BORTHWICK, H. A. Thresher injury in baby lima beans. Jour. Agr. Res., 44:503–510. 1932.

[5]BAINER, ROY, and BORTHWICK, H. A. Thresher and other mechanical injury to seed beans of the lima type. Calif. Agr. Exp. Sta. Bul. 580:1-30. 1934.

containing six bars each mounted with eight teeth to the bar. The teeth of both the cylinder and concave bars were of steel 1 9/16 inches long and 6/16 inch square on the ends. Teeth in the cylinder and concave bars were spaced from 1 1/8 to 1 3/8 inches apart. The clearances when the adjacent cylinder and concave teeth were closest together were from 7/16 to 9/16 inch.

Power for running the machine was supplied by a 2 H.P. motor operated without resistance or any kind of variable speed starter boxes. The calculated peripheral speed of the cylinders was 916 feet per minute which speed seemed to be constantly maintained. This speed was used because of the relatively high percentage of undamaged and low percentage of unthreshed beans previously obtained with it. Bainer and Borthwick[6] found that at higher speeds more lima bean seed damage resulted, while at lower speeds there was a high percentage of unthreshed beans.

An effort was made to feed the beans into the thresher at a uniform rate throughout the experiment. At the end of 1 minute of threshing a container of about 3 pounds capacity was placed under the delivery spout. When this was filled the contents were placed in a sack and labeled. Four similar samples were taken during the continuous operation of the machine.

At the end of about 10 minutes of threshing, the machine was stopped, cleaned, and rubber covers were placed on all the concave teeth. The rubber covers had an outside diameter of 1.4 cm, and an inside diameter of 1.0 cm, with a wall thickness of 0.2 cm, which was slightly less than this when the rubber was stretched over the concave teeth. Unthreshed beans were fed into the machine and samples of the threshed beans were collected at the same time intervals as in the case of the unprotected teeth. The beans were cleaned with a blower, care being taken that only leaves, stems, etc., were blown out but not any cracked beans.

Two hundred gram samples of cleaned beans were then weighed out from each of the 10 samples of threshed beans for the two years. From each sample, all beans showing no external evidence of cracking were removed, weighed, and the results recorded in Table 1. The results of germination tests made in the greenhouse with beans showing no visible cracked seed coats taken from each of 20 samples are shown in Table 2.

Applying Students' pairing method to the results from the 1934 experiment, it appears that there are no significant differences between the amount of external cracking of the beans from unprotected concave teeth and those from rubber-covered teeth. In 1935 a slightly significant difference (odds 19:1) in favor of the rubber-covered concave teeth was obtained (Table 1). The same method indicates that there is no significant difference in the germination of apparently uninjured beans taken from the two types of threshing in either of the two years (Table 2). The absolute difference between the average of rubber- and of steel-threshed beans is the same in both years, i.e., 2.8 grams or 1.4% in favor of the rubber-threshed samples (Table 1).

[6]*Loc. cit.*

TABLE 1.—*The weight in grams of whole beans (no visible cracks) taken from 200-gram samples drawn at stated intervals from thresher with and without rubber-protected concave teeth.*

Sample No.	Threshing time, minutes	Rubber protected		Unprotected	
		1934	1935	1934	1935
I	1	184	189	178	190
II	3	173	190	175	186
III	5	180	189	183	185
IV	7	184	190	175	187
V	9	185	191	181	187

Mean difference in 1934, 2.8 grams in favor of the rubber. $t=1.2384$ for $N=4$. Odds between 3:1 and 5:1.

Mean difference in 1935, 2.8 grams in favor of the rubber. $t=2.8866$ for $N=4$. Odds are slightly more than 19:1 that rubber gives some protection in threshing.

TABLE 2.—*The percentage germination of whole beans (no visible cracks) taken from cleaned samples drawn at stated intervals from a thresher with and without rubber-protected concave teeth.**

Sample No.	Threshing time, minutes	Rubber protected		Unprotected	
		1934	1935	1934	1935
I	1	78	80	80	83.5
II	3	76	82	80	81.5
III	5	82	80	86	82.5
IV	7	84	81	78	81.0
V	9	86	81.5	84	81.5

Mean difference 1934 = —0.4%. $t=0.21$ for $N=4$. Odds about 1:5 that rubber is better than steel

Mean difference 1935 = —1.1%. $t=1.38$ for $N=4$. Odds about 1:4 that rubber is better than steel.

*Based on 100 seed samples in 1934 and 200 seed samples in 1935.

Moisture determinations[7] made on composite samples from the uncovered steel and from the rubber-protected teeth threshed in 1935 indicated that the moisture content of the samples was practically the same, i.e., 8.64% for the non-covered and 8.86% for the rubber-covered.

CONCLUSIONS

The present investigation based on only two seasons' work and with two varietal types of beans indicates that in some cases rubber on the concave teeth may give some slight protection, but probably not enough to justify the expenditure of the time necessary to equip the thresher. It would seem more important to control the cylinder speed of the machine, as well as the distance through which beans drop after leaving the cylinders, and also the hardness of the surface upon which they drop.

[7]Determinations made by L. L. Harter.

Since much of the injury may be due to a crushing or shearing effect upon seeds caught between the moving teeth, it would seem to be practicable to increase the clearance between teeth in case rubber is to be used. Indeed, even an increased damage from crushing or shearing might be expected as a result of decreasing the clearance by adding rubber covering to the teeth. Although rubber covered, the steel beneath would be just as unyielding as though bare.

SOME FACTORS WHICH MODIFY THE RATE AND TOTAL AMOUNT OF INFILTRATION OF FIELD SOILS[1]

G. W. Musgrave and G. R. Free[2]

It has been shown that the relative amount of surface run-off which occurs following precipitation is dominantly affected by the amount of infiltration into the soil profile. Many different factors affect both the infiltration rate and the total amount of infiltration.

The purpose of the study reported herein has been to determine quantitatively the effects of several of the more important of these factors. Particular interest centered in the porosity of the profile, the effect of soil moisture, and the effect of vegetative cover, since these factors are subjected to wide variation in practice, and also since the indicated effects are of large magnitude.

DISCUSSION OF LITERATURE

Bennett (2)[3] presented data obtained from plats at some of the soil erosion experiment stations which proved that close vegetation is very effective in reducing erosion and run-off.

Duley and Miller (4) reported that run-off losses from an uncultivated plat, a plat plowed 4 inches deep, and a plat plowed 8 inches deep over a 6-year period were 49%, 31%, and 28%, respectively of total rainfall.

Slater and Byers (13) showed marked differences in the percolation rates of short open end columns of different soil series. They stated that large numbers of cores should be obtained in attempting to fix field-percolation rates by this method alone because of the wide variation obtained from cores of the same soil.

Auten (1) compared forest and prairie soils from the standpoint of water absorption and reported a much greater capacity for the former soil together with a lower volume weight.

Lowdermilk (7) showed that the effect of forest litter in increasing absorption of water was largely caused by the filtering action of this cover.

Powers (12) found that air pressure or suction applied to a cylinder of oils produced a marked effect on percolation. He also gave the percolation rates for samples of Chehalis loam and Williamette silty clay loam, that of the latter soil being decidedly lower than that of the former. Volume weights were not given.

Buehrer (3) investigated soil structure using equipment to measure the rate of flow of air through soil columns. He reported that the relation of the "structure constant" and porosity was not linear. He also gave the volume rate of air flow for various mixtures of coarse sand and clay, coarse sand and silt, and coarse sand and very fine sand. In all cases the rate was lower for a mixture than for the coarse sand alone, a small amount of the finer material decreasing the rate by a large amount.

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[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Received for publication June 29, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 739.

Horton (5) gave a method for determining the infiltration rate from records of rainfall intensity and run-off. His later publication (6) listed some of the factors affecting the infiltration rate, among which were packing of the soil surface, inwashing of fine materials to pores, soil moisture content, cultivation, and earthworm and insect perforations.

Musgrave (10) demonstrated the value of knowing the infiltration rate when planning an erosion control program. He also compared the infiltration rates of Marshall and Shelby silt loams (11). A description of the equipment used for the investigation was also given. The same equipment was used for the study described in this paper.

Middleton (8) presented the results of a study of several erosible and non-erosible soils. The non-erosible soils had lower volume weights.

Middleton, Slater, and Byers (9) presented the physical and chemical composition of the soils from the different erosion experiment stations along with other data. The Marshall and Shelby silt loams used for the study described in this paper were obtained from the stations at Clarinda, Iowa, and Bethany, Missouri, respectively, and the descriptions and data given are applicable to them.

METHODS

The same equipment was used in this study as is described elsewhere (11). Metal cylinders 6 inches in diameter having comparatively thin walls were jacked into the soil at the location desired. The length of the cylinders used for this study was from 14 inches to 18 inches, giving a soil column 12 inches to 16 inches in length. The length of columns were comparable for any given comparison. In some cases infiltration rates were determined for the cylinders of soil without removing them from the ground. However, for some parts of the study it was more convenient to have the cylinders inside on a base. For columns of this length no noticeable difference in infiltration rate occurred whether the cylinders were used in the ground and then removed to avoid disturbing a plat or were dug up and placed on a base in the laboratory or elsewhere. The equipment as it would be used for cylinders on a base is shown in Fig. 1.

FIG. 1.—Equipment for determining infiltration rates.

A perforated sheet metal disc was placed on top of the soil column so that the water did not become turbid when applied. A self-dispensing 1,000-cc burette or glass tube holding the same amount was inverted over the soil column with the outlet about 6 millimeters above the soil surface. A head of water was thus maintained at 6 millimeters within quite narrow limits and the amount of water necessary to maintain this head because of the loss from infiltration was easily measured and converted to surface inches.

This equipment may readily be used for infiltration studies in plats where soil disturbance must be a minimum. In this case the metal cylinders at the completion of the study are removed from the ground by using a frame that permits

jacking against the soil around the outside of the cylinders which are withdrawn through an annular slot in the frame.

Two soils were used in this study, namely, Marshall and Shelby silt loams. An abbreviated mechanical analysis of those soils taken from Middleton, Slater, and Byers (9) is as follows:

Depth, inches	Gravel and sand, %	Silt, %	Clay, %
	Marshall		
0 13	2.1	59.0	35.3
13–24	1.5	56.5	39.4
	Shelby		
0–7	25.2	44.5	27.0
8 12	19.0	27.1	51.8
12–20	20.1	28.5	50.2
20 24	31.2	26.9	41.8

It is apparent from the analysis that the Marshall is quite uniform in texture as would be expected in a loessial soil. Shelby, however, is derived from Kansan drift and does not show this uniformity. There is considerably more sand and gravel in the Shelby topsoil than in the Marshall, but it is in the subsoil that the difference between the two soils is most striking.

RESULTS

EFFECT OF INCREASED PORE SPACE OBTAINED BY CULTIVATION

Twenty-three cylinders of Marshall silt loam were used for this part of the study. Initial infiltration rates were obtained for the set without disturbing the structure in any way. Forty-eight hours after this initial run a so-called wet run was made. The tubes were then dried by surface drying (keeping the bottoms of the cylinders covered) to a moisture content approximating the original. Each cylinder was then cultivated to a depth of 4 inches and infiltration rates determined as before. The same procedure was repeated for a 6-inch depth of cultivation.

The increased pore space utilized in this study was mechanically obtained by cultivation. Changes in pore space, may, of course, be obtained by other means, such as the incorporation of manure with the soil or the turning under of crop residues.

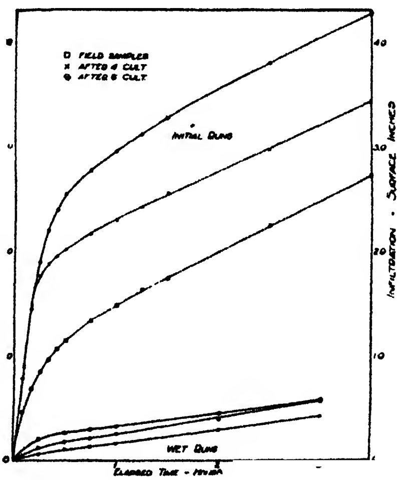

FIG. 2.—Effect of increased pore space (obtained by cultivation) upon the infiltration rate of Marshall silt loam.

Before the first initial run and each of the initial runs for different depths of cultivation, the necessary data were obtained for the determination of volume weights.

The infiltration data from these runs are presented in Table 1 and in the form of curves in Fig. 2. These data were tested for significance by analysis of variance as follows:

Initial Runs

Source of variation	Degree of freedom	Sum of squares	Mean square
Total	68	152.54	——
Cylinders	22	82.37	3.74
Treatments	2	27.60	13.80
Remainder	44	42.57	0.97

$F=\frac{13.80}{0.97}=14.23$ (Showing highly significant differences due to treatments $F=5.12$ for $P=0.01$).

Minimum mean difference for significance ($P=0.05$) $=0.58$
Minimum mean difference for significance ($P=0.01$) $=0.78$

Wet Runs

Source of variation	Degree of freedom	Sum of squares	Mean square
Total	68	13.63	——
Cylinders	22	9.48	0.43
Treatments	2	0.39	0.19
Remainder	44	3.76	0.09

$F=\frac{0.19}{0.09}=2.11$ (Showing non-significant difference due to treatments. $F=3.21$ for $P=0.05$)

The increased pore space obtained by each depth of cultivation has significantly increased infiltration for the 3½-hour initial run. It will be noted, however, both from Table 1 and Fig 2, that most of the differences in rates due to depth of cultivation had largely, if not entirely, disappeared in the first 30 minutes or less of the runs. No significant effects of the treatments are found in the wet runs.

The average of the volume weights of the samples as obtained from the field was 1.25. The range of variation, however, was from 1.17 to 1.32. Various correlations were attempted between these volume weights and infiltration data for the runs on the field samples. Some of the correlation coefficients obtained are presented in Table 2.

The data for the correlation of field weights and total infiltration for the first ½ hour of both initial and wet runs are presented graphically on Fig. 3 along with the calculated regression lines. It is apparent that much of the variation between tubes can be allocated to variation between volume weights.

The fact that highly significant correlations for both initial and wet runs were found between infiltration and field volume weights at the start of the initial run should not be confused with previous data indicating that the effect of increased porosity obtained by cultivation was significant for the initial run and not significant for the wet run. In one case the differences in porosity probably applied

TABLE 1.—*The effect of increased pore space (obtained by cultivation) upon the infiltration rate of Marshall silt loam (field structure).*

	Field samples	Field samples after 4 in. cultivation	Field samples after 6 in. cultivation
Ave. % moisture	27.0	28.2	27.1
Ave. volume weight	1.25	1.17	1.13
Ave. % porosity	52.8	55.8	57.4
Interval, minutes	Initial runs, surface inches per hour		
5	5.52	10.80	9.36
5	2.76	7.08	8.04
5	1.92	3.36	5.40
5	1.44	1.32	3.72
5	1.20	0.96	2.28
5	0.84	0.72	1.80
15	0.80	0.60	0.92
15	0.60	0.52	0.72
15	0.60	0.56	0.68
15	0.44	0.52	0.60
60	0.50	0.43	0.54
60	0.47	0.46	0.47
Total surface inches in 3½ hours	2.72±0.37	3.46±0.24	4.29±0.23
Interval, minutes	Wet runs, 48 hours after initial runs, surface inches per hour		
15	0.88	0.24	0.52
15	0.20	0.20	0.20
15	0.16	0.12	0.16
15	0.08	0.12	0.16
60	0.13	0.14	0.14
60	0.13	0.13	0.18
Total surface inches in 3 hours	0.59±0.08	0.44±0.08	0.58±0.11

TABLE 2.—*Correlation coefficients for various comparisons of volume weights and infiltration.*

Comparison	Correlation coefficient*
Volume weights versus total infiltration for	
A, 3½-hour initial run	—0.53
B, first ½-hour of initial run	—0.69
C, last 2 hours of initial run	—0.43
D, 3-hour wet run	—0.74
E, first ½-hour of wet run	—0.76

*Minimum value for significance (P = 0.05) = 0.40
Minimum value for significance (P = 0.01) = 0.51

to all the soil within the cylinders, while in the other case the changes in pore space obtained by cultivation did not extend below the depth disturbed.

CHANGE IN INFILTRATION RATE OF TWO SOILS CULTIVATED TO SAME DEPTH

The change in infiltration rates of Marshall and Shelby silt loams each cultivated to two different depths is presented in Table 3 and in Fig. 4. During the first part of the initial runs the total amount

infiltered into Shelby is less than that infiltered into the Marshall, but it is later in the run that the difference between the soils becomes

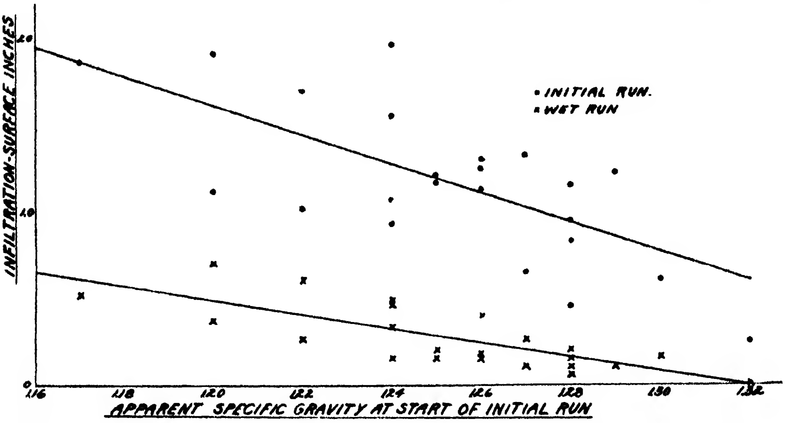

FIG. 3.—Infiltration during first 30 minutes of runs versus apparent specific gravity at start of initial run.

more apparent. The ratio of amounts infiltered during the last hour is in the order of 9:1. Apparently the effect of the cultivation has evidenced itself only for the first part of the initial run as was found in the discussion on this subject above.

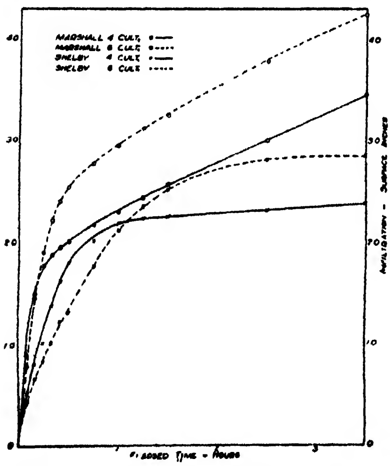

FIG. 4.—A comparison of the change in infiltration rates of two soils each cultivated to two different depths.

It is unfortunate that the wet run for the Shelby soil cultivated to a 4-inch depth was not made 48 hours after the initial run as was the case in the other wet runs. This, however, was impossible owing to the retention of a head of water on the more impervious Shelby. It is readily apparent, however, that the infiltration rate for the two soils during these runs is appreciably different.

EFFECT OF LONG-CONTINUED RUN AND MOISTURE CONTENT

Throughout the preceding subject matter data have been presented for both initial runs and wet runs, the essential difference being the amount of moisture present. Variation in moisture content at the start of a run below a certain value, which seems to be about 30%, apparently has little effect on the infiltration rate of Marshall silt loam. It is logical to assume that this critical moisture content, if it exists at all for other soils, would be different than that for Marshall.

TABLE 3.—*A comparison of the change in infiltration rates of two soils each cultivated to two different depths.*

	Shelby silt loam, 4 in. cultivation	Marshall silt loam, 4 in. cultivation	Shelby silt loam, 6 in. cultivation	Marshall silt loam, 6 in. cultivation
Average % moisture	20.2	28.2	19.5	27.1
Average volume weight	1.28	1.17	1.22	1.13
Average % porosity	51.9	55.8	54.1	57.4
Interval, minutes	Initial runs, surface inches per hour			
5	6.12	10.80	5.04	9.36
5	3.48	7.08	2.88	8.04
5	3.36	3.36	2.64	5.40
5	3.48	1.32	2.04	3.72
5	3.00	0.96	2.04	2.28
5	2.16	0.72	1.08	1.80
15	1.04	0.60	1.76	0.92
15	0.48	0.52	1.48	0.72
15	0.20	0.56	0.96	0.68
15	0.08	0.52	0.64	0.60
60	0.07	0.43	0.30	0.54
60	0.06	0.46	0.04	0.47
Total surface inches in 3½ hours	2.38±0.06	3.46±0.24	2.86±0.14	4.29±0.23
Interval, minutes	Wet runs, 48 hours after initial runs, surface inches per hour			
15	0.32*	0.24	—	0.52
15	—	0.20	0.04	0.20
15	—	0.12	0.04	0.16
15	0.04	0.12	—	0.16
60	0.07	0.14	0.01	0.14
60	0.04	0.13	0.01	0.18
Total surface inches in 3 hours	0.20±0.07	0.44±0.08	0.04±0.02	0.58±0.11

*5-day interval between runs rather than 48 hours in order to allow head of water to disappear.

A certain interval has elapsed between all of the 3½-hour initial runs and 3-hour wet runs and in all cases on Marshall silt loam a reduction in infiltration has been the result. The question arises as to whether such a decrease would have occurred had the time of the initial run been extended. Table 4 and Fig. 5 present data that furnish an answer to this question.

From the table and chart it is apparent that the infiltration rate continued to decline uniformly for a 24-hour initial run, although the decline was comparatively slow after the first 5 hours. The last part of this curve agrees quite well with Horton's (6) use of a straight line. After allowing 6 days to elapse we find that the rates for the wet run were little different from those at the end of the 24-hour initial run. The average moisture content at the start of the initial run was 19.6% and 33.2% at the start of the wet run.

This difference of 13.6% moisture at the start of the two runs differing so greatly in initial infiltration rates is equivalent to approx-

TABLE 4.—*Effect of long-continued run upon the infiltration rate of Marshall silt loam.*

Initial run			
Average % moisture...	19.6		
Average volume weight	1.31		
Average % porosity...	50.6		
Interval	Surface inches per hour	Interval	Surface inches per hour
5 minutes	8.16	11th hr.	0.27
5 minutes	2.88	12th hr.	0.25
5 minutes	1.68	13th hr.	0.27
5 minutes	1.08	14th hr.	0.26
5 minutes	1.20	15th hr.	0.25
5 minutes	0.96	16th hr.	0.24
15 minutes	0.80	17th hr.	0.24
15 minutes	0.68	18th hr.	0.23
2nd hr.	0.46	19th hr.	0.23
3rd hr.	0.41	20th hr.	0.23
4th hr.	0.33	21st hr.	0.23
5th hr.	0.31	22nd hr.	0.24
6th hr.	0.31	23rd hr.	0.24
7th hr.	0.27	24th hr.	0.22
8th hr.	0.29		
9th hr.	0.26	Total surface inches in 24 hours. . . .	8.02±0.98
10th hr.	0.28		

Wet run, 6 days after initial run, average % moisture 33.2			
	Interval, minutes	Surface inches per hour	
	15	0.32	
	15	0.28	
	60	0.21	
	60	0.19	
	60	0.22	
	60	0.21	
	60	0.21	
Total surface inches in 5½ hours		1.19+0.12	

imately 2.50 surface inches of water. It will be noted from Fig. 5 that the difference between the total amounts of infiltration at the end of 5½ hours is about 2.20 surface inches. This suggests that the relatively high rates at the start of the initial runs are largely due to greater volume of pore space available for infiltration at that time. This pore space eventually becomes filled with water and the rate approaches a constant. Swelling of colloids, trapping of air within the soil, and bacterial action causing gas formation are other factors that probably contribute to the changes in rates that have been noted.

It is interesting that in the last three or four years of soil moisture determinations made for various field conditions throughout the season at this station, few samples have had a moisture content above 31%. Apparently, rapid drainage into drier soil below usually takes place at or near this point.

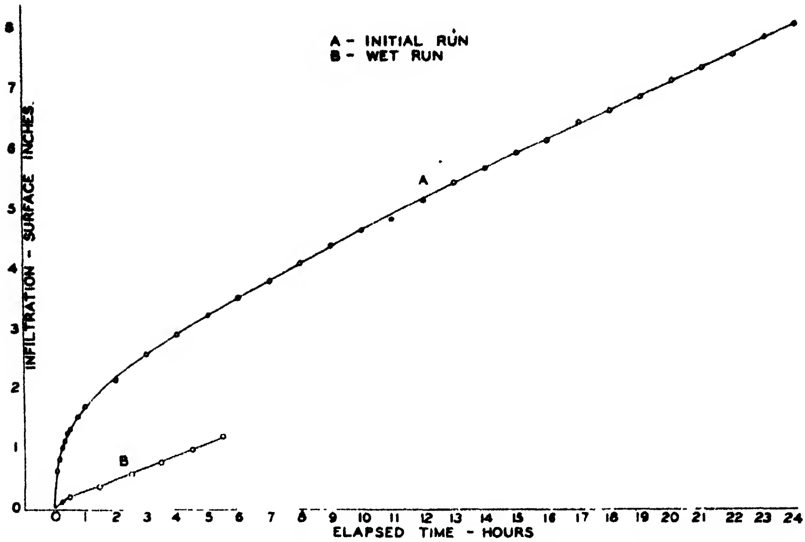

FIG. 5.—Effect of long-continued run upon the infiltration rate of Marshall silt loam.

EFFECT OF CLOSE VEGETATION

It is a well-recognized fact that close vegetation, such as bluegrass sod or alfalfa, has a pronounced effect in reducing erosion and a somewhat less effect in reducing run-off. Run-off, of course, bears an inverse relation to infiltration and the effect of close vegetation on infiltration was a part of this study.

Both initial runs and wet runs were made for different types of vegetation and the data are presented in Table 5. These runs were made within a few days of each other in October without any rainfall during the period. The bluegrass and alfalfa were both well established, it being the third year for both.

It is apparent that close vegetation has not increased the total infiltration for the 3½-hour initial run enough compared to the total infiltration for soil without cover to account for the great differences in run-off that are found in the field and described by Bennett (2) and others.

The significance of the differences presented in Table 5 has been tested by analysis of variance. All differences between initial runs were found to be not significant and the only significant differences between wet runs were those between soil with close vegetative cover and soil with no cover. Total infiltration during the initial runs with close vegetative cover is about 50% greater than total infiltration with no cover and over 200% greater during the wet runs. The relative changes in infiltration rates seem worthy of further analysis and data from Table 5 are summarized for this purpose in Table 6.

TABLE 5.—*The effect of vegetation upon the infiltration rate of Marshall silt loam (field structure).*

	Alfalfa	Bluegrass	Desurfaced sod	Fallow
Average % moisture	14.8	18.4	20.9	27.0
Interval, minutes	Initial runs, surface inches per hour			
5	12.00	11.64	2.52	5.52
5	2.64	2.76	1.20	2.76
5	1.56	1.80	0.84	1.92
5	1.56	1.08	1.32	1.44
5	1.20	1.20	0.72	1.20
5	1.20	1.08	0.84	0.84
15	1.08	0.92	0.92	0.80
15	0.76	0.80	0.72	0.60
15	0.84	0.72	0.72	0.60
15	0.80	0.72	0.60	0.44
60	0.77	0.71	0.54	0.50
60	0.74	0.65	0.57	0.47
Total surface inches in 3½ hours	4.06±0.73	3.78±0.85	2.47±0.47	2.72±0.37
Interval, minutes	Net runs, 24 hours after initial runs, surface inches per hour			
15	1.44	0.56	0.48	0.88*
15	0.72	0.52	0.24	0.20
15	0.68	0.40	0.24	0.16
15	0.68	0.44	0.20	0.08
60	0.67	0.47	0.17	0.13
60	0.69	0.72	0.19	0.13
Total surface inches in 3 hours	2.24±0.59	1.67±0.66	0.65±0.18	0.59±0.08

*48-hour interval between runs here rather than 24 hours.

TABLE 6.—*Summary of data from Table 5 on relative changes in infiltration rates.*

	Amount of infiltration		
	Last 2 hours initial run, surface inches	Last 2 hours wet run, surface inches	Reduction, % of initial run
Bluegrass	1.36	1.19	12
Alfalfa	1.51	1.36	10
Desurfaced sod	1.11	0.36	68
Fallow	0.97	0.26	73

The infiltration rate for the close vegetation is well sustained, whereas for the other treatments it is markedly reduced. This is probably due to the filtering action of the litter always found on and mixed with the surface soil where vegetation of this kind is grown. This does not imply turbidity of the applied water in the other cases, but it is logical to assume that soil particles from the surface of soils not covered with such litter can be more easily carried along with the infiltering water. Clogging of pores would result and a greater

percentage change in amount infiltered would naturally follow, as has been shown by other workers.

A further comparison between the bluegrass and the desurfaced sod is particularly interesting since the original cover was the same in both cases. The desurfacing consisted of removing the cover and not more than 1 inch of soil. If the prime effect of bluegrass upon infiltration was caused by root penetration, we would probably not expect to find the differences so apparent in the above tables.

Another effect of close vegetation in reducing run-off cannot be demonstrated without resorting to data from areas of different slope length. Comparative run-off data for plats cropped the same and with the same degree of slope but differing in slope length are given in Table 7. These plats are located at the Soil Erosion Experiment Station at Clarinda, Iowa.

TABLE 7.—*The effect of vegetation on run-off on Marshall silt loam, 9% slope, July 1, 1934 to December 31, 1935.*

Crop	Slope length, feet	Run-off, surface inches	Number of times run-off occurred
Fallow	3	15.32	43
Corn	3	9.81	37
Bluegrass	3	6.59	33
Corn	72.6	5.07	22
Bluegrass	72.6	0.59	4

Considering the 3-foot plats first, corn has reduced run-off to approximately 64% of that from fallow. A further reduction of 21% occurs with bluegrass sod cover. The run-off from bluegrass is 67% of that from corn.

When the length of the slope is extended to 72.6 feet, however, the run-off from bluegrass is only 12% that from corn. The run-off from the corn plat 72.6 feet long is 52% that from the corn plat 3 feet long, while the run-off from the bluegrass plat 72.6 feet long is only 1% that from the bluegrass plat 3 feet long. It is apparent that slope length is an important factor and produces a greater effect with close vegetation than with a row crop.

A logical conclusion, therefore, is that a very important effect of close vegetation is to reduce the velocity of surface movement and thus allow more time for infiltration to take place. It would be expected that such an effect would be appreciably less on the short slope on which differences in time would be too slight to affect greatly the total amount of infiltration. On the other hand, the effect of increased time would be vastly greater on the longer slope with consequent marked reduction in run-off. Such expectations are in full harmony with the data.

CONCLUSIONS

Of the various factors which may modify the rate of infiltration of water into field soils, the percentage of porosity is one of the most dominant. Increasing the average percentage of pore space of cores

of field structure through surface cultivation has markedly increased the rate of infiltration. While there are many possible ways of increasing porosity, only one was included in the study reported herein, namely, various depths of cultivation. On Marshall silt loam the average rates over a 3½-hour period were as follows: Without cultivation, 0.78 inch per hour, with 4-inch cultivation, 0.99 inch per hour; and with 6-inch cultivation, 1.23 inches per hour.

During the first 30 minutes following the application of water to Marshall silt loam the effects of cultivation were quite pronounced. After this initial period, however, the effects of increased porosity induced by cultivation diminished repidly. On the Shelby silt loam, however, the effect persisted about 1½ hours, or approximately three times as long as on the Marshall. Over a 3½-hour period following the initial application of water the rates for the two soils were rather similar, the ratio of Marshall to Shelby for the period being about 1½:1. For the latter part of this period of operation, however, the rates diverged widely averaging about 9:1.

In the long-continued application (24 hours) Marshall silt loam showed a fairly constant rate of intake following the initial period. There was a gradual decline in rate, however, giving the curve a slight downward trend. The curves reported herein differ from those of Horton in two respects. They show a rapid intake during the initial period and a slight downward trend toward the close of the period. Horton's, derived from hydrographs of large watersheds, show a practically straight line relationship throughout.

The long-continued application with its slightly downward trend shows a reduction in infiltration rate which results from a high soil moisture content. In the present work with Marshall silt loam the reduction apparently became appreciable at or slightly above a moisture content of 30% on a dry weight basis.

In this study little evidence is found that close vegetation such as bluegrass and alfalfa increases the rate of infiltration enough to account for the marked control of surface run-off that is characteristic of such cover. The rate, however, is sustained over a longer period of time, due probably to reduced turbidity as has been shown by Lowdermilk and other workers. The reduction in run-off, which as has been pointed out by Bennett, is almost universal in all comparisons of close vegetation with other treatments, may be accounted for at least in part by a lower velocity of run-off which gives in effect a greater time for infiltration. The effect of lower velocity becomes particularly marked when studied for areas of appreciable size. There are undoubtedly other factors which are not touched upon in this study which also have a definite bearing upon the marked control of run-off which is affected by various types of close vegetation.

The study as a whole would indicate that, although the infiltration rate may be greatly modified by changes in porosity induced by one or another means, and relatively by soil moisture content or vegetative cover, yet the dominant factor may well be the soil type, at least insofar as comparison between the permeable Marshall and the relatively impermeable Shelby are concerned.

The transitory effects of cultivation and low soil moisture contents

doubtless account to a large degree for variations in run-off which are commonly found for similar rains. They cannot be relied upon, however, in the design of erosion control measures for which purpose infiltration rates of a conservatively low magnitude should be used.

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SOIL LIMING INVESTIGATIONS: II. THE INFLUENCE OF LIME ON THE SORPTION AND DISTRIBUTION OF PHOSPHORUS IN AQUEOUS AND SOIL COLLOIDAL SYSTEMS[1]

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LIMING soils is generally recognized to influence the availability of soil phosphates, but the exact nature of this effect is not clearly understood (7)[3]. Certain investigators have shown that liming increased the phosphates in water extracts (2) and in the soil solution (10); others have reported under certain conditions a decrease in soluble phosphates (3, 8), while another (9) has shown that either a decrease or increase in available phosphates might occur, depending on the amount of lime applied and the chemical composition of the soil colloid. These conflicting results may be more apparent than real when the conditions under which the investigations were conducted are properly considered and evaluated. Thus, the amounts of lime required for saturating the soil colloids (6), the resulting effect on the fixation of phosphates, and the chemical composition of soil colloids should be considered in any attempt to clarify the lime-phosphate situation.

It is well established that "liming injury" occurs in some soils. This injury has been attributed to a lack of soluble soil phosphates (9) or to a "disturbed phosphate nutrition" which may be somewhat temporary (7). Nutrients other than phosphorus are known to enter into the results from liming soils but these were not considered in this investigation.

The behavior of phosphate ions in the presence of Ca and Mg ions derived from liming materials is of considerable importance in the problem of supplying plants with phosphorus. Furthermore, it is important to know the distribution of the phosphate ions in soils as related to base saturation and reaction. There are considerable data available on the titration of H_3PO_4 with Ca, but none have been found for Mg. The work of Gaarder (3) shows the solubility of the various basic phosphates but does not give the titration curves or results comparable with those of this investigation.

The titration of H_3PO_4 with $Ca(OH)_2$ was first shown to yield an abnormal curve by Wendt and Clark (11). They found that the normal end points of the electrometric titration curve were obtained for the monovalent and tri-valent salts but not for the di-valent. Other more comprehensive studies have been reported (1, 4, 5) which substantiated the above anomaly.

The reaction of soils of the humid section varies over the pH range of 4.0 to 8.0. It is known that the addition of the usual amounts of superphosphate and rock phosphate to soils have practically no effect

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on soil reaction. It is further known that the concentration of phosphate ions in soils is influenced by reaction.

In view of the above statements it seemed pertinent that this investigation be conducted to determine the effect of lime on the concentration and distribution of P in aqueous and soil systems.

PLAN OF INVESTIGATION

The influence of Ca and Mg on the distribution of P in aqueous systems was determined by titrating H_3PO_4 with $Ca(OH)_2$, $Mg(HCO_3)_2$ and a mixture of the two. The Ca titrations were made without the presence of CO_2 and after equilibration with the CO_2 of the atmosphere. The Mg titration was equilibrated with the CO_2 of the atmosphere. Serial titrations were made and allowed to come to equilibrium after which the solutions were analysed for ions of H, Ca or Mg, and P, and the solid phase for the ratios of base, Ca or Mg, to P. The latter determined the nature of the P salt formed, while the analysis of the solution phase gave the solubility of the ions at different reactions.

The influence of Ca on the sorption and distribution of P by electrodialized soil colloids was determined by equilibrating systems with H_3PO_4 and Ca. The Ca-sorption capacities of the H-colloids were determined as previously reported (6), and brought to varying degrees of saturation with Ca. The detailed procedure is given later for each study.

RESULTS

DISTRIBUTION OF PHOSPHORUS IN AQUEOUS SYSTEMS

The distribution of P and Ca when H_3PO_4 is titrated with $Ca(OH)_2$ with and without access to the CO_2 of the air.—Phosphoric acid was added to definite increments of $Ca(OH)_2$ solution and diluted to 100 ml. volume in tightly stoppered flasks. The pH values of the solutions were determined after 24 and 48 hours. The curve is shown in Fig. 1. An aliquot of the solution or suspension was taken after 48 hours and centrifuged. The liquid phase was analysed for P and the solid phase for Ca. The data from these determinations are given in Table I. A similar study, as described above, was set up in aeration flasks and equilibrated with the CO_2 of the air. These data are included in Table 1. The contents of the aeration flasks were then saturated with CO_2 and the pH values determined. The latter values are in the lower curve of Fig. 2. The titration curve in Fig. 1 shows the normal end points for the mono- and tri-calcium salts but does not show a definite end point for the di-calcium salt. The latter must be obtained from further analytical data. This anomaly was quite misleading at first. However, from the data in Table 1 it is seen that the following distribution occurs:

Range in pH	3.0	3.0 to 5.0	5.0 to 6.4	Above 6.4
Ca salts	None	$Ca(H_2PO_4)_2$	$CaHPO_4$	Ca_3PO_4

The mono-calcium salt was completely soluble, but the di-calcium salt decreased in solubility quite rapidly with increasing Ca concentration and alkalinity. The tri-calcium salt was only slightly soluble as would be expected above pH 6.4. The smooth curve of the soluble P within the pH range 6.4 to 7.34 indicated the presence of

a single phosphate ion. There were definite breaks on either end of this range which support this view.

The soluble Ca increased linearly to pH 6.40, where it passed through a maximum, then decreased (precipitated as $CaHPO_4$) with a break in the smooth curve at the end point of the di-calcium salt. It continued to decrease until it passed through a minimum at slightly above pH8.0, the end point of the tri-calcium salt. The latter increase in Ca was due to excess Ca over the added P.

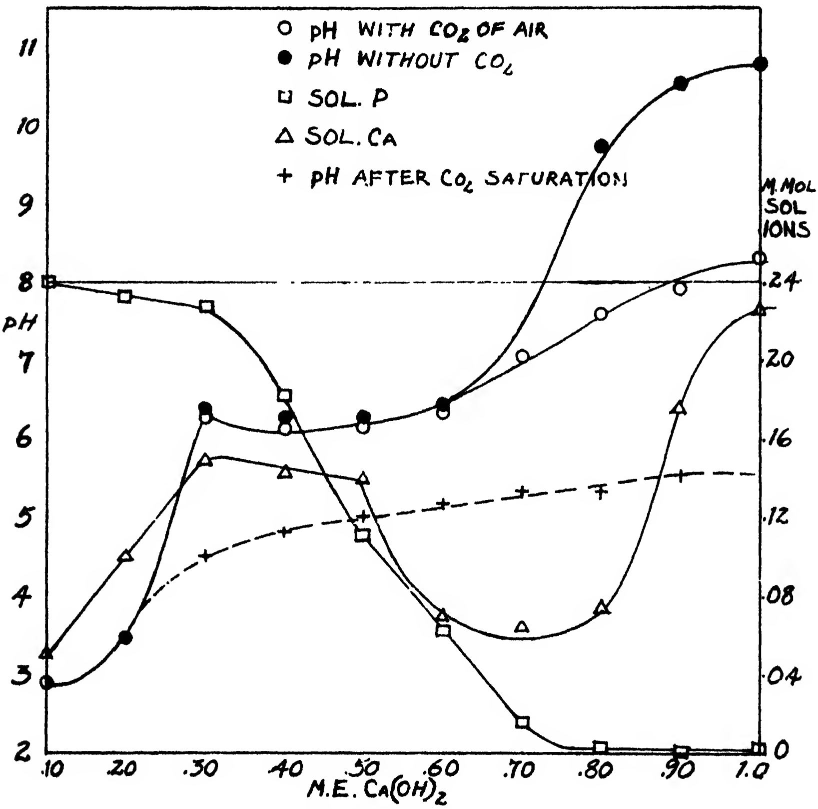

FIG. 1.—Titration curves of the H_3PO_4 and $Ca(OH)_2$ solutions.

The ratio Ca/P of the precipitated salt (Table 1) shows the distribution of the various calcium phosphate salts and their mixtures. That is, at pH 6.40 the ratio Ca/P was approximately 1.0, the theoretical value for Ca_3PO_4; also at approximately pH8.0 the ratio was 1.5, the theoretical value for Ca_3PO_4. The mixture was found between these limits.

In the presence of atmospheric CO_2 (.0003 $A.CO_2$) the pH curve (Fig. 1) is identical to that without CO_2 below pH 6.5 as previously discussed. Above pH 6.5 the two curves are quite different in that the former approaches a maximum at the reaction of a saturated solution of $CaCO_3$, while the latter approaches the value of saturated

TABLE 1.—*Titration of ortho phosphoric acid and calcium hydroxide with and without access to carbon dioxide, Ca and P as millimols per 100 cc.*

Added			No. CO_2						Equilibrated with CO_2 of air						
No.	$Ca(OH)_2$	H_3PO_4	pH		Soluble		Precipitated		pH			Soluble		Precipitated	
			24 hrs.	48 hrs.	Ca*	P	Ca	Ca/P	24 hrs.	48 hrs.	72 hrs.	Ca*	P	Ca	Ca/P
1	0.05	0.233	3.00	2.99	0.05	0.233	0.00	—	2.99	N.D.†	2.90	0.050	0.240	0.00	—
2	0.10	0.233	3.57	3.60	0.10	0.233	0.00	—	3.56	N.D.	3.48	0.100	0.233	0.00	—
3	0.15	0.233	6.40	6.40	0.15	0.233	0.00	—	6.40	6.40	6.28	0.150	0.228	0.00	—
4	0.20	0.233	6.40	6.27	0.115	0.142	0.085	0.93	6.30	6.33	6.12	0.143	0.182	0.057	1.11
5	0.25	0.233	6.35	6.27	0.110	0.100	0.140	1.05	6.52	6.42	6.18	0.139	0.111	0.111	0.91
6	0.30	0.233	6.54	6.42	0.077	0.056	0.223	1.26	6.77	6.60	6.34	0.070	0.063	0.230	1.35
7	0.35	0.233	7.33	7.04	0.017	0.008	0.333	1.48	7.27	7.16	6.99	0.065	0.016	0.285	1.31
8	0.40	0.233	9.91	9.72	0.035	0.003	0.365	1.58	7.78	7.70	7.60	0.075	0.003	0.325	1.41
9	0.45	0.233	10.54	10.50	—	N.D.	N.D.	—	7.90	7.97	7.91	0.177	0.001	0.273	1.17
10	0.50	0.233	10.74	10.75	—	N.D.	N.D.	—	8.34	8.38	8.32	0.227	0.003	0.273	1.18

*By difference in added and precipitated calcium.
†Not determined

$Ca(OH)_2$. The solubility of phosphorus was slightly greater in the presence of CO_2 than where no CO_2 was present, but the data are quite similar indicating the same distribution of phosphorus compounds. The atmospheric CO_2 also increased the solubility of Ca appreciably and the results for the two are again similar. It is interesting to follow the course of the soluble Ca curve in Fig. 1. There are

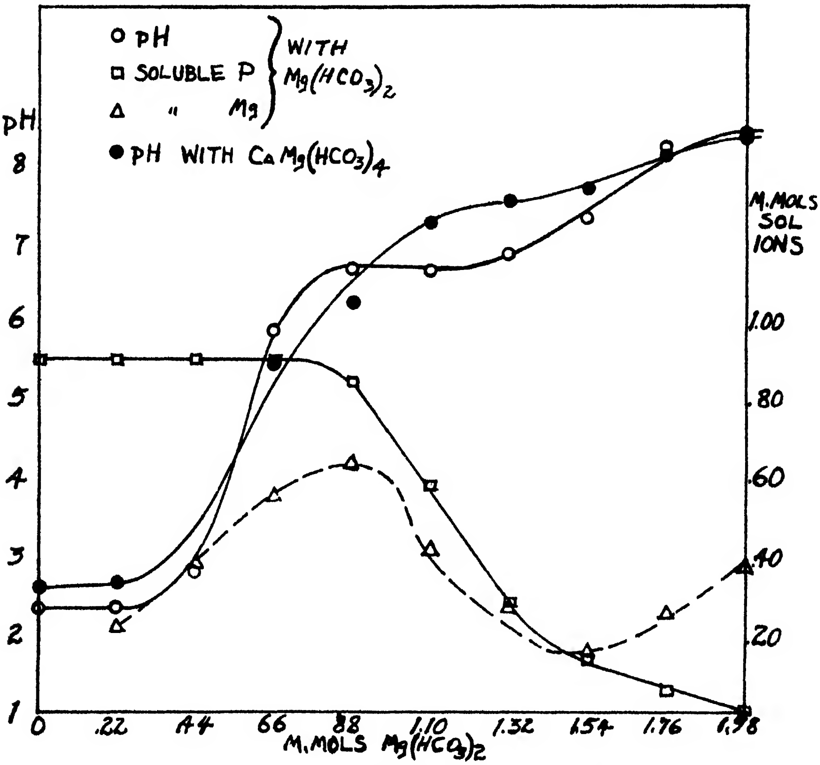

FIG. 2.—Titration curves of H_3PO_4 solutions with $CaMg(HCO_3)_4$ and $Mg(HCO_3)_2$.

three pronounced breaks in this curve, which lag somewhat behind the end points of the titration curve. The Ca/P of the precipitate again conforms to the theoretical value up to the end point of the titration; beyond this it decreases due to the increased solubility of Ca in the absence of P ions.

In the presence of an atmosphere of CO_2 (saturated) the pH values decrease to that of a saturated $Ca(HCO_3)_2$ solution with phosphate (Fig. 1). All of the Ca and P was soluble under these conditions.

It may be seen, from the evidence reported here, that in the majority of native soils, pH range 4.75 to 6.5, the $HPO_4^{=}$ ion is predominant. The CO_2 partial pressure is highly significant in the solubility of P and hence the utilization of P by plants. With high concentrations of CO_2, even in heavily limed soils, it is most likely that the

$HPO_4^{=}$ ion is predominant and is associated with the di-calcium salt. It was further shown that the solubility of P was decreased to practically a trace by adding an excess of $Ca(OH)_2$, and the H ion concentration primarily determined the distribution of the different P ions.

The distribution of P and Mg in the titration of H_3PO_4 with Mg $(HCO_3)_2$.—This study, conducted as a serial titration similarly to that for Ca, previously discussed, was made on the solutions and suspensions equilibrated with the CO_2 of the air. The titration curve is shown in Fig. 2 along with the soluble P and Mg. The behavior of the magnesium phosphate was in general quite similar to that of the calcium phosphate. However, the amount of soluble P and Mg was greater than in the Ca system. The $Mg(HPO_4)_2$ was completely soluble in the concentrations present, while there was an appreciably higher solubility of both the di- and tri-basic salts of Mg as compared with Ca. The analytical data for the Mg and P in the solid phase indicated that the solid phase was slightly more basic than the di-basic salt in the range pH 6.50 to 6.84 and slightly more basic than the tri-basic salt above pH 6.84. The curve for soluble Mg passes through a distinct maximum immediately before the end point of the tri-basic salt. The solubility of the phosphate ion was not depressed until the alkaline range was approached.

The Distribution of phosphorus and Ca in the titration of H_3PO_4 with $CaMg(HCO_3)_4$ in the presence of the CO_2 of the air.—The procedure in this study was similar to that in the previous Ca and Mg studies. The analytical results are shown graphically in Fig. 2. It may be seen that the titration curve is quite different from the two preceding curves where Ca and Mg were added separately. The pH curve does not show the minimum at the transition point of the di- and tri-basic salts as in the preceding cases but does show an inflection point between pH 7.0 and 8.0. The solubility of the phosphate ion was greater in the alkaline range in this case than when Mg alone was present. The explanation for this may be due to the fact that the solubility of the carbonates and hydroxides of Ca and Mg are reversed with respect to one another, namely, the solubility of $Ca(OH)_2$ is nearly 200 times that of Mg, while $MgCO_3$ is only 10 times that of Ca. It was found that the content of Ca in the solid phase, precipitate, was greater than the Mg except at pH 7.66 where equal amounts were fixed with the P.

The results from this study are of considerable interest in that Ca and Mg ions are added to soils in the case of liming with dolomite. The greater solubility of P where Ca and Mg are present is of practical importance in liming.

INFLUENCE OF CALCIUM SATURATION AND CARBON DIOXIDE PARTIAL PRESSURE ON SORPTION AND DISTRIBUTION OF PHOSPHORUS BY ELECTRODIALIZED SOIL COLLOIDS

Procedure used in studies with soil colloids.—One gram of electrodialized soil colloid in suspension was equilibrated with Ca, CO_2 of

the air, and water to yield systems of varying degrees of Ca saturation. A standard solution of H_3PO_4 was added to the suspensions in amounts equal to 10 millimols per 100 grams colloid and the suspensions were made up to constant volume. The suspensions were then aerated until equilibrium was established and analyses for H ion, soluble Ca, and soluble P were made on an aliquot. The remaining suspension was then saturated with CO_2 for a period of 1 hour and another aliquot removed and analysed as above.

The pH values were determined on the suspensions with the glass electrode and then the liquid phase was obtained by the centrifuge for determinations of soluble Ca and phosphorus. In this study the term fixation includes the P removed from solution both by sorption and precipitation. The soil colloids used were described previously (6) and represented two soils with low and two with high SiO_2/R_2O_3.

Results obtained with soil colloids of low SiO_2/R_2O_3.—The Hartsells and Norfolk colloid with SiO_2/R_2O_3 of 1.70 and 1.10, respectively, were used in this study. The analytical data from the Norfolk colloid are given in Table 2 and the distribution of phosphates with the Hartsells colloid is shown graphically in Fig. 3. It is seen that the results are in general quite similar for the two colloids in that the H-colloids sorbed a large portion of the added P. The addition of Ca increased the fixation of P directly with the amount added. The inflection in the curve (Fig. 3) is due to the transition of the di-valent phosphate ion as discussed above. Results from the CO_2-saturated suspensions, lower curve, are taken to represent the phosphates sorbed by the colloid. The difference between the two curves, shaded area, represents the P precipitated as $Ca_3(PO_4)_2$ and possibly as hydroxyapatite. The data from the suspensions saturated with CO_2 indicate that lime has practically no influence on the P sorbed by these colloids.

Studies with soil colloids of high SiO_2/R_2O_3.—The colloids from the Delta and Lufkin soils with ratios of 2.70 and 3.82, respectively, were taken for these studies. The results (Table 3 and Fig. 4) indicate strong similarity in the behavior of the two colloids. Relatively little P was sorbed by the H-clays, but the addition of Ca increased the fixation very rapidly as shown by the steep portion of the curves. The addition of CO_2 and formation of H_2CO_3 brought the precipitated Ca-phosphates into solution, shaded portion between the curves, thereby permitting the determination of the P sorbed by the Ca-colloids. Calcium increased the sorption of P very greatly by these colloids of high SiO_2/R_2O_3.

DISCUSSION

INFLUENCE OF LIME ON P FIXATION

It is interesting to note that Ca-phosphates begin to precipitate at approximately 25, 37.5, 50, and 75% Ca saturation in case of the Hartsells, Norfolk, Delta, and Lufkin colloids, respectively. All of these points fall close to a reaction of pH 6.5 where, as shown above, phosphates begin to precipitate. The SiO_2/R_2O_3 also increases directly in the above order, an observation substantially similar to that pre-

TABLE 2.—*The influence of calcium saturation and carbon dioxide partial pressure on the sorption and distribution of phosphate in the presence of Norfolk electrodialized colloid. Ca in M.E. and P in millimols per 100 grams colloid.*

Added				Air equilibrium					CO₂ saturated				
				pH	Soluble ions		Sorbed and precipitated		pH	Soluble ions		Sorbed	
No.	% Ca sat.	Ca	P		Ca	P	Ca	P		Ca	P	Ca	P
1	0	0	10.0	3.90	0	1.92	0	8.08	3.56	0	0.72	0	9.28
2	12.5	7.5	10.0	4.50	4.0	1.60	3.5	8.40	4.00	2.6	1.00	4.9	9.00
3	25.0	15.0	10 0	5.33	—	1.60	—	8.40	4.35	6.0	1.36	9.0	8.64
4	37.5	22.5	10.0	6 30	6.0	1.28	16.5	8.72	4.60	10.8	1.84	11.7	8.16
5	50.0	30.0	10.0	6.95	7.6	1.12	22.4	8.88	4.76	15.2	1.44	14.8	8.56
6	75.0	45.0	10.0	7 45	12.4	1.12	32.6	8.88	5 03	26.8	1.76	18.2	8.24
7	100.0	60.0	10.0	7.82	13.2	0.40	46.8	9.60	5.19	44.0	1.76	16.0	8.24
8	125.0	75.0	10.0	8.10	22.0	0.13	53.0	9.87	5.27	55.6	1.52	19.4	8.48

TABLE 3.—*The influence of calcium saturation and carbon dioxide partial pressure on the sorption and distribution of phosphate in the presence of Lufkin electrodialized colloid. Ca in M.E. and P in millimols per 100 grams colloid.*

Added				Air equilibrium					CO₂ saturated				
				H+	Soluble ions		Fixed (sorbed and precipitated)		H+	Soluble ions		Sorbed	
No.	% Ca sat.	Ca	P	pH	Ca	P	Ca	P	pH	Ca	P	Ca	P
1	0	0	10.0	3.11	0	5.54	0	4.46	2.92	0	5.82	0	4.18
2	25	23.1	10.0	3.58	2.0	3.79	21.1	6.21	3.44	2.0	4.11	21.1	5.89
3	50	46.2	10.0	4.76	4.0	—	42.2	—	4.30	3.0	1.58	43.2	8.42
4	62.5	57.7	10.0	5.39	4.0	2.08	53.7	7.92	4.60	6.0	1.12	51.7	8.88
5	75.0	69.3	10.0	6.23	5.0	1.20	64.3	8.80	4.75	10.0	0.96	59.3	9.04
6	87.5	80.8	10.0	7.15	6.0	1.28	74.8	8.72	5.02	17.0	1.31	63.8	8.69
7	100.0	92.5	10.0	7.83	8.0	1.20	84.5	8.80	5.25	30.0	1.21	62.5	8.79
8	125.0	115.6	10.0	8.39	21.0	0.40	94.6	9.60	5.45	54.0	1.71	61.6	8.29

viously reported with the use of bentonite containing low and high Fe contents (8). There is little evidence in the present study to show OH ion replaced the PO_4 ion at high concentrations of Ca as was reported in the above investigation.

It is believed that the procedure used in the present investigation comes nearer to determining the P sorption capacity by Ca-colloids

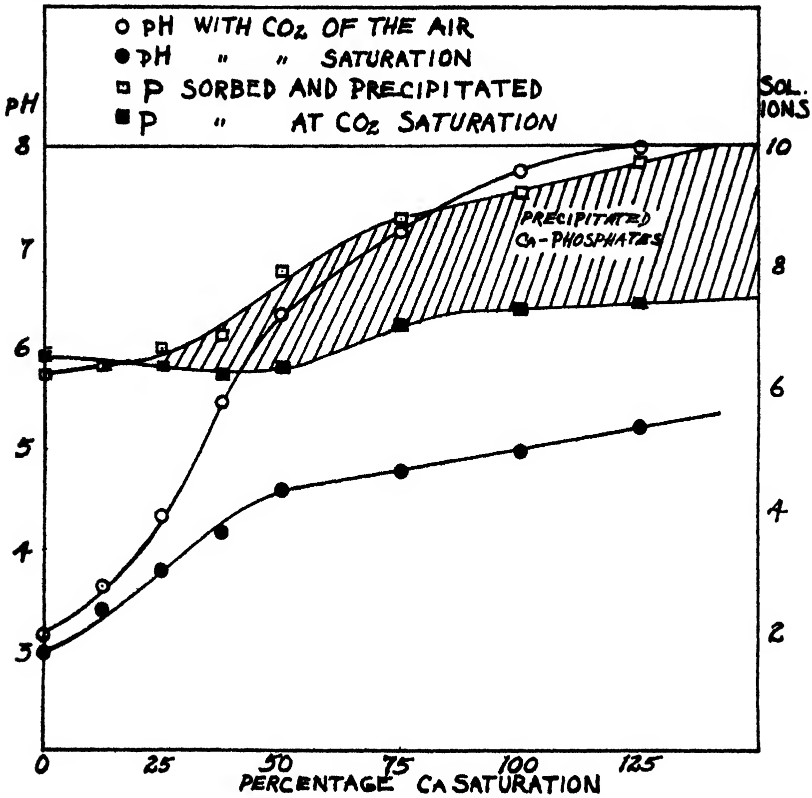

FIG. 3.—The influence of Ca on the sorption of phosphate by Hartsells electrodialized colloid.

than any method heretofore presented. The method is applicable to systems where Ca does or does not play a rôle as shown by the colloids of low and high SiO_2/R_2O_3. The importance of the CO_2 content of the system is further emphasized by the results obtained by this procedure. It is very likely that the precipitated Ca-phosphate in the soils would become available to plants, while the Fe and Al or sorbed phosphates would be relatively less available. The availability of the phosphates fixed was measured to some extent in this study where the suspensions were equilibrated with atmospheric CO_2 and a saturated solution of CO_2; this statement is based on the fact that soils contain high concentrations of CO_2.

It seems logical that either the mono-, di, or tri-valent phosphate

ion would be sorbed by soil colloids depending on the reaction of the medium since it was shown that each salt was predominant over a certain range. It is further known that the sorption of an ion is dependent on its concentration and certainly the latter is dependent on reaction. The tri-valent ion would be more strongly held by the colloid than the di-valent, and the latter more strongly than the mono-

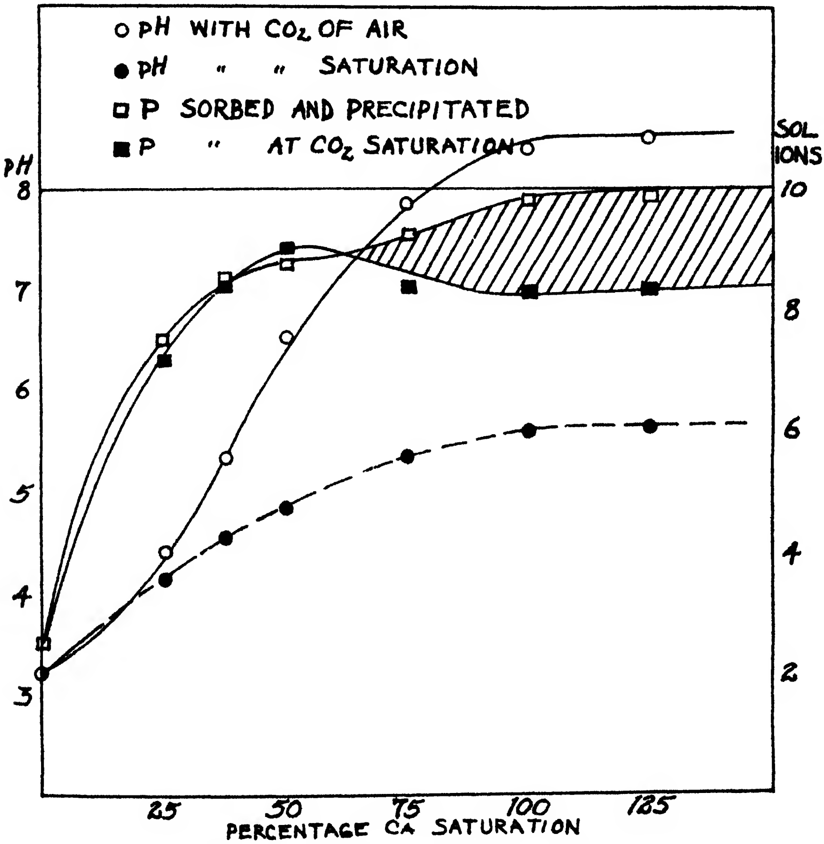

FIG. 4.—The influence of Ca on the sorption of phosphate by delta electrodialized colloid.

valent; undoubtedly this phenomenon would influence the availability of sorbed phosphate ions. The effect of liming on the valence and its effect on the availability of the sorbed phosphate ion cannot be answered from the data of this study, but the possibility of its importance should be considered.

The results obtained in this investigation seem to indicate that liming injury, which might be attributed to a decrease in available phosphates in acid soils would occur only on those of high SiO_2/R_2O_3 and, furthermore, such injury would approach a maximum near pH 6.5. Soils with high SiO_2/R_2O_3 and moderately high in degree of

base saturation show no liming injury since they are natively saturated with bases above the point where lime would increase the sorption of phosphates. This statement is substantiated by the results reported in the first paper of this investigation (6) and by data from a continuation of this work which will be published soon. Evidence has been obtained to show that over-liming injury may be due in part to the lack of available minor elements.

CONSIDERATION OF RESULTS OBTAINED DURING THIS INVESTIGATION WITH THOSE FROM OTHER INVESTIGATORS

It was pointed out above that Scarseth (8) attributed liming injury to insoluble phosphates both from sorption by colloids and precipitation as calcium phosphates. These two sources of injury may be termed "sorption injury" and "precipitated calcium-phosphate injury", respectively. The former resulted from small applications of lime, while the latter was obtained by over liming.

Data were obtained to show that sorption injury occurred with colloids of low iron content (high SiO_2/R_2O_3) but not with those containing high iron (low SiO_2/R_2O_3). This was substantiated by the results obtained in this investigation with two soil colloids of low and two with high ratios. From the standpoint of phosphate sorption injury the results may be taken to apply primarily to the soils of the Black Belt section in so far as Alabama is concerned and not to the majority of the soils of Alabama since the SiO_2/R_2O_3 is low.

Over liming soils results in precipitated calcium-phosphate injury according to Scarseth (9), and is independent of soil type. The only condition for this type of injury is that the soils contain free $CaCO_3$ from excessive liming. This conclusion was drawn from the studies which showed that water-soluble phosphates were precipitated as insoluble $Ca_3(PO_4)_2$ and hence believed to be unavailable to plants, a true condition where little or no CO_2 is present, but not where appreciable evolution of CO_2 occurs as in most soil-plant systems. The results obtained in the present investigation show that the freshly precipitated calcium phosphates are soluble in CO_2 systems and indicate that over-liming injury may not be due to insoluble phosphates. Over liming acid soils in the presence of soluble phosphates will precipitate the calcium phosphates in very finely divided particles distributed throughout the soil, but it is believed that the H_2CO_3 present in the soil solution would render these phosphates available to plants. The latter consideration was perhaps overlooked in the conclusions drawn by those who attribute over liming injury to P deficiency where soluble phosphates were present, especially in the light of recent data which show that excessive liming does not cause injury to crops on all soils some of which are natively low in available P.

The investigation by Pierre and Browning (7) showed that lime increased the water-soluble phosphates in soils where injury was obtained while certain other soil amendments increased the soluble phosphates and overcame this injury. The data presented show no tendency of phosphate sorption injury since the smaller increments

of lime increased crop yields. This might be attributed to the added phosphate or to the relatively low SiO_2/R_2O_3 of the soils.

It may be seen, then, that liming may increase or decrease the availability of phosphates under certain conditions and when previous apparently conflicting results are considered and the factors involved properly evaluated, they appear to be compatible.

SUMMARY

A study was made to determine the effect of Ca and Mg ions on the distribution of phosphates in aqueous and soil-colloidal systems. The Ca and Mg ions were added in increments to make a complete titration curve. The statements listed below summarize the results of this investigation.

1. The formation of calcium phosphates in aqueous solutions was as follows: Mono-basic, pH 3.0 to 5.0; di-basic, pH 5.0 to 6.4; and tri-basic, above pH 6.4.

2. The formation of $CaHPO_4$ is transitory and during the transition the H ion concentration of the solution increases.

3. The presence of an excess of Ca in alkaline medium forms a more basic salt than the tri-basic phosphate. This salt is probably hydroxy-apatite, $3\ Ca_3(PO_4)_2.Ca(OH)_2$.

4. The distribution of magnesium phosphates was quite similar to that of calcium except for the greater solubility of the former.

5. The distribution of phosphates in the presence of $Ca.Mg(HCO_3)_4$ was different from that of either Ca or Mg alone. The solubility of the phosphates over the complete range was greater where Ca and Mg were present than where Mg was added alone.

6. The influence of Ca on the fixation of phosphates was studied with colloids of low and high SiO_2/R_2O_3 by the use of technic whereby the amount sorbed was separated from that precipitated. It was found that Ca had practically no effect on the sorption of phosphates by colloids of low SiO_2/R_2O_3, but with those of high ratio the phosphates sorbed were greatly increased. In all cases where atmospheric CO_2 was present the excess P was precipitated, but where the system was saturated with CO_2 the latter was in solution.

7. Results obtained during this investigation indicate that liming acid soils causes a decrease in available P by increasing the sorption by the soil colloids only on soils of high SiO_2/R_2O_3. This effect reaches a maximum below the Ca saturation point.

8. Previous apparently conflicting data on the influence of lime on phosphate solubility appear to be compatible when interpreted in the light of the present investigation.

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THE BASE EXCHANGE CAPACITY OF DECOMPOSING ORGANIC MATTER[1]

H. C. Millar, F. B. Smith, and P. E. Brown[2]

THE organic matter fraction of soils has been shown by various investigators (3, 19, 2, 4, 1, 5, 9, 20, 16)[3] to be responsible for a large part of the base exchange capacity of soils.

McGeorge (4) noted a linear relation between the exchange capacity and the carbon content of 20 soils, but no such relationship existed between the base exchange capacity and the nitrogen content or the carbon-nitrogen ratio. He concluded that lignin, ligno-hemicellulose, and ligno-cellulose fractions function largely as the exchange compounds of soil organic matter. He observed (5) that the exchange capacity of ligno-humate was larger than the exchange capacity of lignin extracted from the same soil. Xylan, a constituent of hemicellulose, was found to have an exchange capacity which was increased by chemical humification. The increase in exchange capacity of decomposing alfalfa was attributed to a differential decomposition resulting in a concentration of lignin-like bodies in the residues and the variation in the properties of lignin was attributed to the number of hydroxyl and methoxyl groups in the molecule.

Mitchell (9) concluded that two fractions of soil organic matter have base exchange properties, namely, the hemicellulose-containing fraction and the lignin fraction of which the latter is more important. There appeared to be no relation between the nitrogen content of the lignin-humus and its base exchange capacity.

Powers (15), working with sweet clover, oat straw, flax shives, sphagnum moss, sphagnum peat, saw grass, peat, and wheat during decomposition, noted that the exchange capacity increased, that conditions favoring decomposition favored an increase in exchange capacity, and that the increase in lignin content tended to parallel the increase in base exchange capacity.

McGeorge (6) pointed out that lignin may exist in the plant in active and inactive forms with the base exchange capacity varying accordingly.

Waksman and Iyer (21) observed that the base exchange capacity of ligno-protein preparations increased with an increase in the protein content.

Müller (10), studying manure and straw, found an increase in exchange capacity with decomposition. He concluded that the property of base exchange in isolated fractions of organic matter may be attributed to certain groups, such as the hydroxyl and carboxyl,

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[3]Figures in parenthesis refer to "Literature Cited", p. 765.

rather than to specific substances. Cellulose as filter paper or reprecipitated cellulose had no exchange capacity, but when treated with strong sulfuric acid and alkali had a base exchange capacity greater than natural or purified humus.

McGeorge (7) studied seedlings of corn, cowpeas, rye, wheat, oats, and alfalfa and observed that the base exchange capacity of the different materials varied with the kind and part of the plants.

Powers (16) showed that organic matter treatments to soils gave indications of increased nitrogen and organic matter contents and base exchange capacity.

Few studies have been made of the base exchange capacity of the tops or roots of mature plant materials either before or during decomposition. These experiments were planned, therefore, to determine the base exchange capacity of natural and decomposed plant materials, to study the relationship of the base exchange capacity to other properties of the plant material, and to study the biological decomposition of lignin.

EXPERIMENTAL

The materials selected for study were oat straw, wheat straw, sudan grass, cane sorghum, flax, cornstalks, millet, hemp, soybeans, alfalfa, sweet clover, and red clover. The tops, leaves, and stems were harvested, dried, and passed through a hammer mill. The materials were then brought to the laboratory and ground to pass a 40-mesh screen.

The 12 plant materials were analyzed for total carbon, total nitrogen, alcohol-benzene-soluble fraction, acid-hydrolyzable fraction, lignin, and base exchange capacity. Duplicate 200-gram portions of each of the air-dry plant materials were placed in 2-quart Mason fruit jars. Five grams of calcium cyanamid were added to the material in each jar and the moisture content adjusted to 80%. The materials were kept at a temperature of 26°C. After 67, 137, and 210 days the contents of the jars were spread out in pans to air dry. At each date the materials were passed through a 40-mesh screen, thoroughly mixed, samples taken, the remainder replaced in the jars, and the moisture content adjusted to 80%. The samples taken were analyzed for lignin and base exchange capacity.

The base exchange capacity of the plant materials was determined by a modification of the barium acetate method (8). The alcohol-benzene-soluble fraction, the acid-hydrolyzable fraction, and the lignin were determined by a modification of the method of Ritter, Seborg, and Mitchell (11, 12, 13, 14, 17) as follows: Two-gram samples of the oven-dry materials were extracted for 6 hours with a 1:2 alcohol-benzene mixture. After noting the loss in weight, the samples were placed in hot water for 3 hours before subjecting them to 72% sulfuric acid for 2 hours at 6°C. The acid was now diluted to a 3% solution and the samples were boiled under a reflux condenser for 4 hours. The ash-free lignin was determined on the basis of the oven-dry sample. The difference between the sum of the lignin and alcohol-benzene soluble material and the sample taken was called acid-hydrolyzable material.

Total carbon was determined by the dry combustion method and total nitrogen was determined by the Gunning-Hibbard method. The results are presented in Tables 1, 2, 3, and 4 and Figs. 1, 2, 3, 4, 5, 6, and 7.

RESULTS

The data in Table 1 show the variations in the nitrogen content, the carbon content, the lignin content and the base exchange capacity of the 12 materials under study. The legumes possessed a higher exchange capacity than the non-legumes. The relation between the nitrogen content and the exchange capacity of these materials is shown in Fig. 1 and the correlation was highly significant. The ex-

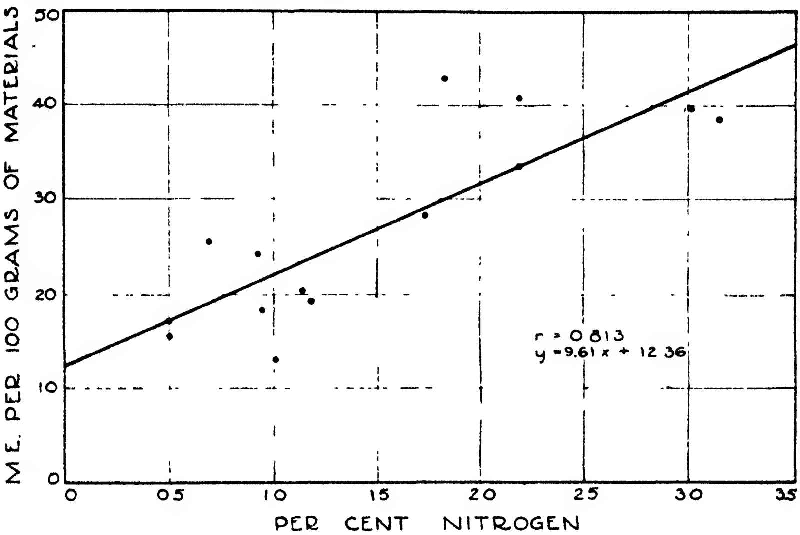

FIG. 1.—Relation between the nitrogen content and the base exchange capacity of plant materials (original materials).

change capacity of these materials was correlated with the content of lignin, but the correlation was just significant (Fig. 2). The data in the table show that no such relation existed between the exchange

TABLE 1.—*Analyses of original plant materials (oven-dry basis).*

Plant material	N, %	C, %	Alcohol-benzene soluble material, %	Hydrolyzable material, %	Ash-free lignin, %	M. E. Ba per 100 grams
Oat straw	0.61	39.00	1.77	80.01	15.98	25.54
Wheat straw	0.50	38.27	1.85	78.74	15.48	15.89
Sudan grass	1.06	40.30	3.20	80.96	13.53	13.03
Cane sorghum	0.87	39.11	6.01	76.98	14.56	16.92
Flax	1.73	39.70	5.85	77.15	15.17	28.09
Cornstalks	1.20	38.11	2.71	82.82	13.19	18.96
Millet	1.17	38.47	6.81	79.52	11.81	20.09
Hemp	0.88	38.92	4.80	78.00	16.96	24.33
Soybeans	1.85	36.41	2.19	78.93	17.50	43.02*
Alfalfa	3.07	38.19	3.18	78.35	17.94	39.34
Sweet clover	3.14	38.35	5.09	80.38	14.39	38.16
Red clover	2.20	39.14	6.08	76.42	14.40	40.60

*Partially decomposed.

capacity and the carbon content, acid-hydrolyzable fraction, or the amount of alcohol-benzene-soluble material.

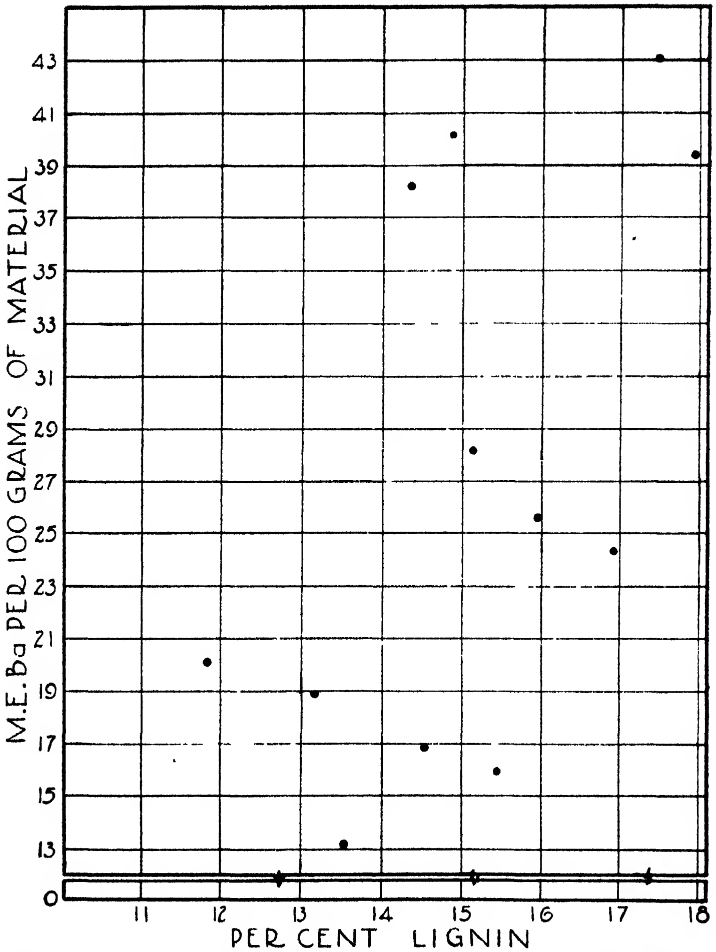

FIG. 2.—Relation between the base exchange capacity and lignin content of plant materials (original materials).

The data in Tables 2 and 3 and Figs. 3, 4, and 5 show that the exchange capacity of the materials increased as the decomposition proceeded, but the relative position with regard to exchange capacity shifted as decomposition progressed. Oat straw was seventh lowest in exchange capacity before decomposition, for example, but after 210 days it had the highest exchange capacity (Fig. 5). The relation between the increase in exchange capacity and the loss in weight from decomposition, calculated as percentage of the original material, is shown in Fig. 6. The loss in weight varied only slightly, the range being from about 55% to 66%. On the other hand, the exchange

TABLE 2.—*Analyses of plant materials (oven-dry basis) before and after treatment.*

Plant materials	Original plant materials					After 67 days		After 137 days		After 210 days				
	Weight in grams	Alcohol-benzene-soluble material %	Hydrolyzable fraction %	Ash-free lignin %	M. E. Ba per 100 grams	Weight in grams	M. E. Ba per 100 grams	Weight in grams	M. E. Ba per 100 grams	Weight in grams	Alcohol-benzene-soluble fraction %	Hydrolyzable fraction %	Ash-free lignin %	M. E Ba per 100 grams
Oat straw. . .	187.72	1.77	80.01	15.98	25.54	154.89	33.09	103.70	74.25	68.19	1.06	68.83	20.33	130.45
	187.72	1.77	80.01	15.98	25.54	156.61	32.90	114.15	66.56	72.53	1.21	70.61	21.46	124.57
Wheat straw. . .	187.14	1.85	78.74	15.48	15.89	143.29	20.32	102.27	46.67	74.08	1.52	62.57	23.74	67.91
	187.14	1.85	78.74	15.48	15.89	145.11	20.74	91.76	44.80	68.53	1.05	60.10	24.01	71.80
Sudan grass .	185.52	3.20	80.96	13.53	13.03	124.34	25.48	89.86	54.75	64.13	0.79	65.57	26.23	95.56
	185.52	3.20	80.96	13.53	13.03	122.41	24.81	84.00	56.40	64.83	1.03	66.71	25.90	88.36
Cane sorghum	186.22	6.01	76.98	14.56	16.92	123.02	30.71	86.26	47.67	69.64	0.81	60.78	29.19	102.86
	186.22	6.01	76.98	14.56	16.92	127.52	30.80	95.34	46.10	64.87	0.32	62.18	28.82	90.81
Flax .	186.42	5.85	77.15	15.17	28.09	148.48	32.52	100.89	57.29	77.75	1.07	71.60	23.01	83.53
	186.42	5.85	77.15	15.17	28.09	140.90	32.82	106.41	66.94	90.18	0.99	71.04	23.98	89.55
Cornstalks.	186.46	2.71	82.82	13.19	18.96	115.00	31.81	79.22	54.80	60.23	0.00	70.59	24.77	98.74
	186.46	2.71	82.82	13.19	18.96	113.18	32.48	83.60	54.26	62.14	0.00	69.87	25.17	94.27
Millet.	186.68	6.81	79.52	11.81	20.09	115.03	23.70	82.83	51.47	60.74	1.36	72.32	21.62	92.93
	186.68	6.81	79.52	11.81	20.09	110.42	24.45	76.16	53.30	61.20	1.44	70.74	23.02	93.35
Hemp . . .	186.26	4.80	78.00	16.96	24.33	134.10	21.99	104.10	30.90	74.24	1.20	69.10	28.07	58.97
	186.26	4.80	78.00	16.96	24.33	128.87	22.67	102.86	30.63	73.53	0.80	68.48	29.43	57.80
Soybeans . .	186.90	2.19	78.93	17.50	43.02	132.95	43.87	99.72	74.11	75.80	0.64	63.13	20.48	98.89
	186.90	2.19	78.93	17.50	43.02	144.47	45.96	102.67	72.95	72.17	1.20	64.22	20.48	90.81
Alfalfa.	184.00	3.18	78.35	17.94	39.34	109.27	46.70	79.69	52.62	65.27	1.16	73.78	24.07	88.25
	184.00	3.18	78.35	17.94	39.34	115.96	46.48	78.69	51.36	64.16	1.11	71.86	25.39	87.74
Sweet clover. . .	185.76	5.09	80.38	14.39	38.16	111.74	48.71	80.93	56.54	65.14	2.17	70.97	22.54	87.64
	185.76	5.09	80.38	14.39	38.16	115.05	52.25	80.03	59.98	58.45	1.05	77.17	21.12	89.68
Red clover. . . .	184.86	6.08	76.42	14.40	40.60	132.33	45.71	89.99	78.21	70.43	0.15	63.51	22.85	104.63
	184.86	6.08	76.42	14.40	40.60	127.42	47.69	94.58	72.74	72.12	0.10	63.32	22.71	107.04

capacity varied over quite a wide range. The non-legumes, except hemp, increased in exchange capacity during decomposition more than did the legumes. This was not caused by high final values of the non-legumes but by their low initial values.

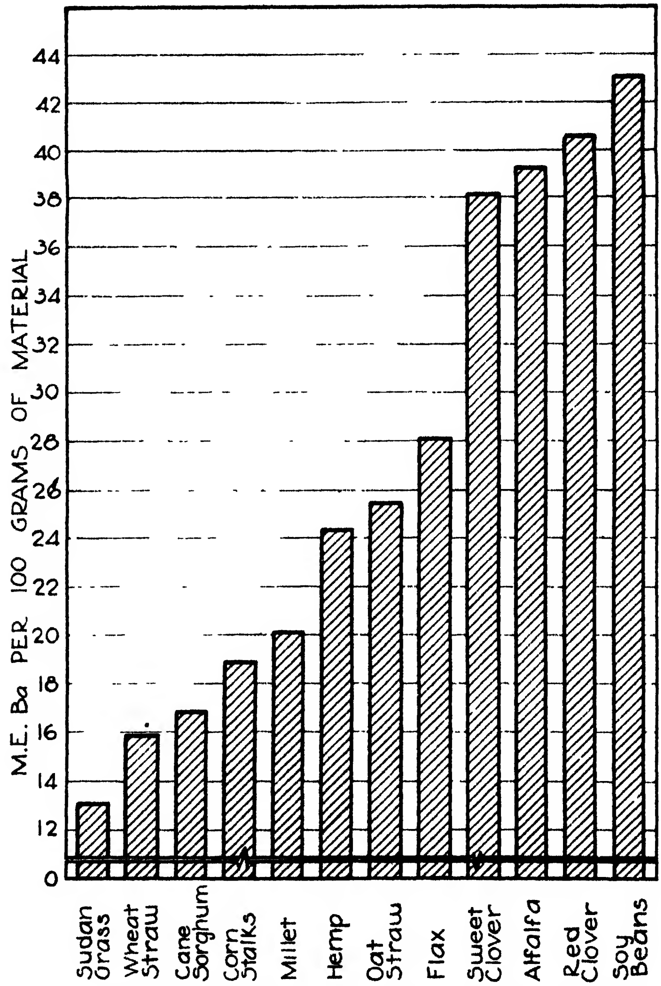

FIG. 3.—The base exchange capacity of original plant materials.

The percentage increase in base exchange capacity and the percentage increase in lignin content after decomposition were calculated and a simple correlation made (Table 4 and Fig. 7). A correlation coefficient of .63, a highly significant value, was obtained. This indicates that the increase in base exchange capacity can be attributed, at least partly, to the increase in the lignin content of the decomposed materials. However, the increase in exchange capacity

was so much larger than the increase in lignin, it would seem that the absorptive capacity of lignin has been increased during the decomposition.

The data in Table 3 show that considerable decomposition of all

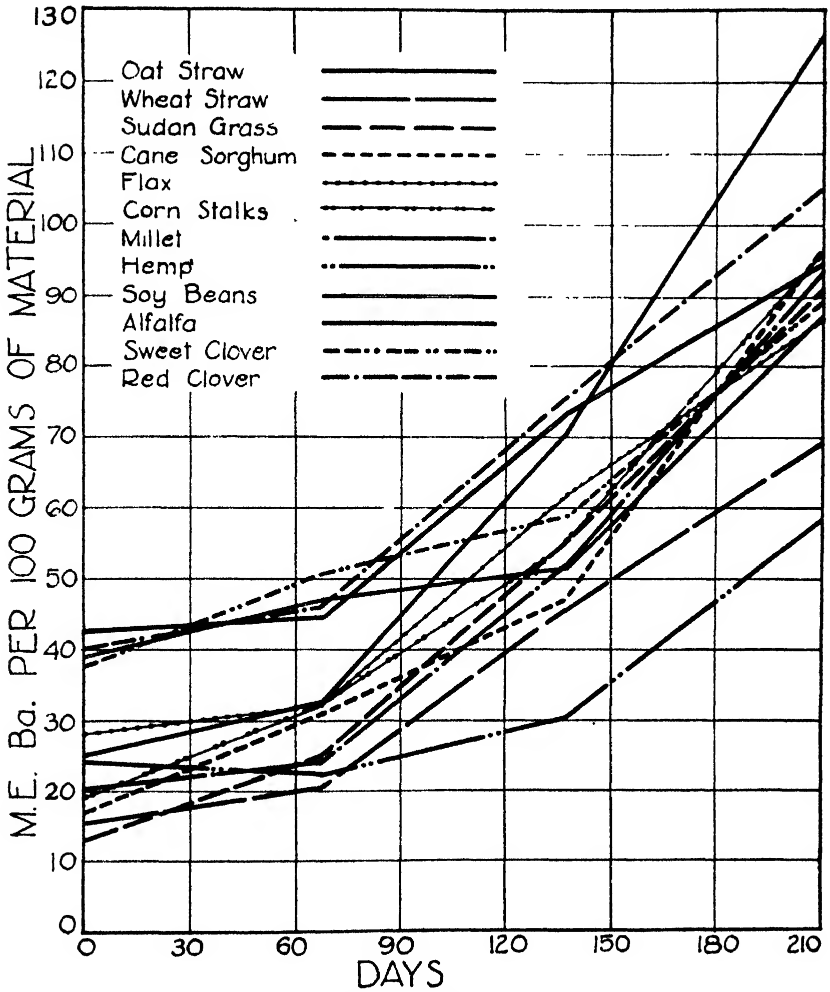

FIG. 4.—Base exchange capacity of plant materials during decomposition.

fractions occurred, the alcohol-benzene-soluble material being decomposed to the greatest extent. The lignin showed the lowest percentage decomposition, but the loss of lignin through decomposition was relatively large. The percentage decomposition of lignin ranged from 24.71% with one sample of cane sorghum to 54.80% with one sample of soybeans. These results indicate a fairly rapid loss of lignin from plant materials decomposing at a temperature of 26°C.

TABLE 3.—*The decomposition of various*

Plant materials	Original material				After 210 days	
	Weight in grams	Alcohol-benzene-soluble fractions, grams	Hydro-lyzable fraction, grams	Ash-free lignin, grams	Weight in grams	Alcohol-benzene-soluble fraction, grams
Oat straw.....	187.72 187.72	3.32 3.32	150.19 150.19	29.99 29.99	68.19 72.53	0.72 0.87
Wheat straw..	187.14 187.14	3.46 3.46	147.35 147.35	28.95 28.95	74.08 68.53	1.12 0.71
Sudan grass...	185.52 185.52	5.93 5.93	150.19 150.19	25.10 25.10	64.13 64.83	0.50 0.66
Cane sorghum	186.22 186.22	11.19 11.19	143.35 143.35	27.11 27.11	69.94 64.87	0.56 0.20
Flax	186.42 186.42	10.90 10.90	143.82 143.82	28.27 28.27	77.75 90.18	0.83 0.89
Cornstalks ...	186.46 186.46	5.05 5.05	154.42 154.42	24.39 24.59	60.23 62.14	0.00 0.00
Millet......	186.68 186.68	12.71 12.71	148.44 148.44	22.04 22.04	60.74 61.20	0.82 0.88
Hemp.......	186.26 186.26	8.94 8.94	145.28 145.28	31.58 31.58	74.42 73.53	0.89 0.59
Soybeans....	186.90 186.90	4.09 4.09	147.52 147.52	32.70 32.70	75.80 72.17	0.48 0.86
Alfalfa......	184.00 184.00	5.85 5.85	144.16 144.16	33.00 33.00	65.27 64.16	0.75 0.71
Sweet clover	185.76 185.76	9.45 9.45	149.31 149.31	26.73 26.73	65.14 58.46	1.41 0.61
Red clover...	184.86 184.86	11.23 11.23	141.27 141.27	26.61 26.61	70.43 72.12	0.10 0.13

DISCUSSION OF RESULTS

The base exchange capacity of the mature plant materials varied with different plants but was not correlated with the carbon contents of the plant materials, while a highly significant correlation was found with the nitrogen contents. McGeorge (4) found no such relation in his studies on soil humus.

The question of whether the nitrogen compounds in the plant materials have a high base exchange capacity or whether their presence increased the exchange capacity of the lignin and hemicelluloses was not answered. However, Waksman and Iyer (21) have shown that the base exchange capacity of ligno-protein preparations increased with an increase in the protein content.

fractions of plant materials (oven-dry basis.)

of decomposition		Loss in weight			Decomposed in 210 days		
Hydro-lyzable fraction, grams	Ash-free lignin, grams	Alcohol-benzene-soluble fraction, grams	Hydro-lyzable fraction, grams	Ash-free lignin, grams	Alcohol-benzene-soluble fraction, %	Hydro-lyzable fraction, %	Ash-free lignin %
46.93	13.96	2.60	103.26	16.13	78.31	68.75	53.78
51.21	15.56	2.45	98.98	14.43	73.79	65.90	48.11
46.35	17.18	2.34	101.00	11.37	67.63	68.54	39.27
41.18	16.45	2.75	106.17	12.50	79.47	72.05	43.17
42.05	16.82	5.43	108.14	8.28	91.56	72.00	32.98
43.24	16.79	5.27	106.95	8.31	88.87	71.20	33.10
42.50	20.41	10.63	100.85	6.70	94.90	70.33	24.71
40.33	18.69	10 99	103.02	8.42	98.21	71.86	31.05
55.66	17.89	10.07	88.16	10.58	92.38	61.29	36.71
64.06	21.62	10.01	79.76	6.35	91.83	55.45	23.52
42.51	14.91	5.05	111.91	9.68	100.00	72.47	39.36
43.41	15.64	5.05	111.01	8.95	100.00	71.88	36.39
43.92	13.13	11.89	104.52	8.91	93.39	70.41	40.42
43.35	14.08	11.83	105.09	7.96	93.07	70.79	36.11
51.42	20.88	8.05	93.86	10.70	90.04	64.60	33.88
50.35	21.63	8.35	94.93	9.95	93.40	65.34	31.50
47.85	15.52	3.61	99.67	17.18	88.26	67.56	52.53
46.34	14.78	3.23	101.18	17.92	78.97	68.58	54.80
48.15	15.71	5.10	96.01	17.29	87.17	66.59	52.39
46.10	16.29	5.14	98.06	16.71	87.86	68.02	50.63
46.22	14.68	8.04	103.09	12.05	83.07	69.04	45.08
45.11	12.34	8.84	104.20	14.39	93.54	69.78	53.83
44.73	16.09	11.23	96.54	10.52	99.10	68.33	39.53
45.66	16.37	11.10	95.61	10.24	98.84	67.67	38.46

The variability in the relation between the base exchange capacity and the lignin content indicates that other factors than the mere presence of lignin are responsible for the exchange capacities of the plant materials. Some of these factors (4, 10) include the form in which the lignin occurs and the part played in base exchange by the hemicellulose (5, 9) fraction. It has been shown (10) that cellulose as finely divided filter paper has no exchange capacity, while oxidized and humified cellulose does have a base exchange capacity.

The fact that the plant materials increased in exchange capacity many times more than they decreased in weight or increased in lignin content indicates that the portions of the organic matter responsible for the base exchange capacity were changed qualitatively during decomposition. A study of the methoxy or hydroxy content

TABLE 4.—*Percentage increase in lignin and percentage increase in base exchange capacity of plant material during 210 days decomposition.*

Plant materials	Lignin			Base exchange capacity		
	Original %	Decomposed %	Increase %	Original M.E. per 100 grams dry material	Decomposed M.E. per 100 grams dry material	Increase %
Oat straw	15.98	20.33	27.00	25.54	130.45	410.00
	15.98	21.46	34.00	25.54	124.57	387.00
Wheat straw	15.48	23.74	53.00	15.89	67.91	327.00
	15.48	24.01	55 00	15.89	71.80	351.00
Sudan grass	13.53	26.23	93.00	13.03	95 56	633.00
	13.53	25.90	91.00	13.03	88.36	578 00
Cane sorghum	14.56	29.19	100 00	16.92	102 66	506.00
	14.56	28.82	97 00	16.92	90.81	436.00
Flax	15 17	23.01	51.00	28.09	83.53	197.00
	15.17	23 98	58.00	28.09	89.55	218.00
Cornstalks	13.19	24.77	87.00	18.96	98 74	420.00
	13.19	25.17	90.00	18.96	94.27	397.00
Millet	11.81	21.62	83.00	20 09	92 93	362.00
	11.81	23.02	94.00	20.09	93.35	364.00
Hemp	16.96	28.07	65.00	24.33	58.97	142.00
	16.96	29.43	73.00	24.33	57 80	137.00
Soybeans	17.50	20.48	17.00	43 02	98.89	129.00
	17.50	20.48	17.00	43.02	90.81	111 00
Alfalfa	17.94	24.07	34.00	39.34	88.25	124.00
	17.94	25.39	41.00	39.34	87 74	123.00
Sweet clover	14.39	22.54	56.00	38.16	87.64	129.00
	14.39	21.12	46.00	38.16	89.68	135.00
Red clover	14.40	22.85	58.00	40.60	104.63	157.00
	14.40	22.71	57 00	40.60	107.04	163.00

of the materials as they decomposed might have shown some correlation with the base exchange capacity. The increase in exchange capacity was significantly correlated with the increase in the lignin contents of the samples.

The base exchange capacity of plant materials did not show the same relationship to one another after decomposition as before composting. However, in the beginning and during the first stages of decomposition the legumes had a higher base exchange capacity than the non-legumes. These high values in the exchange capacity of the legumes associated with their rapid initial decomposition

should have some practical significance in soils in the retention of liberated cations.

The alcohol-benzene-soluble fraction was found to decompose more rapidly than the acid-hydrolyzable material or the lignin. The lignin was the least decomposed. The results indicate a fairly rapid loss of lignin from plant materials decomposing at 26°C.

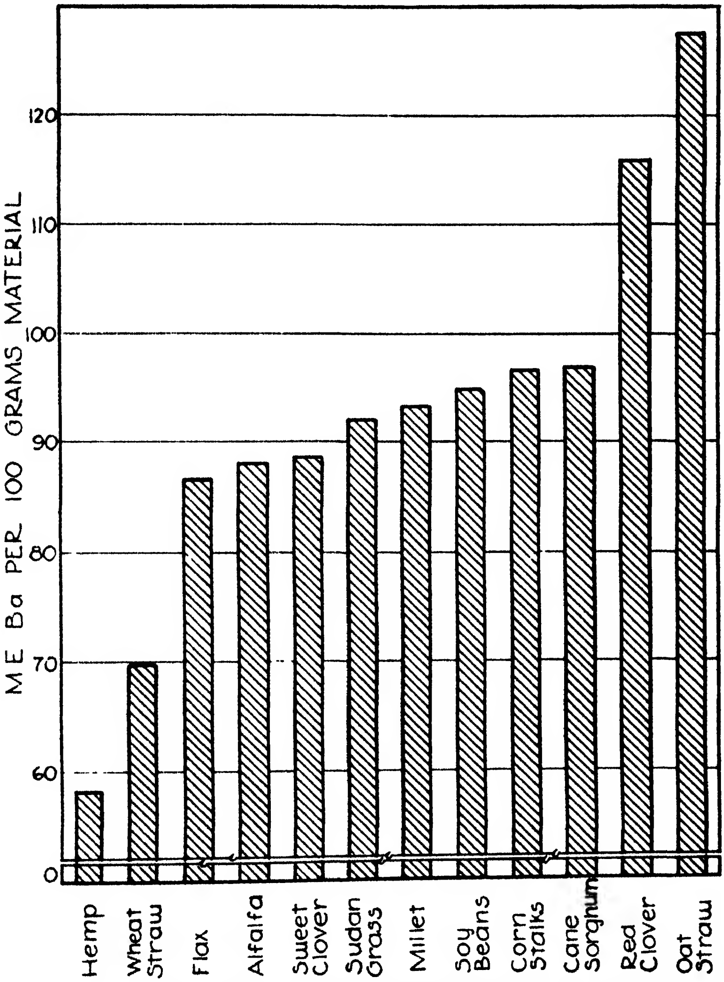

FIG. 5.—Base exchange capacity of plant materials after 210 days decomposition.

SUMMARY AND CONCLUSIONS

The base exchange capacity and the nitrogen, carbon, and lignin contents of oat straw, wheat straw, sudan grass, cane sorghum, flax, cornstalks, millet, hemp, soybeans, alfalfa, sweet clover, and red clover were determined on the mature plant materials before

composting and after 210 days of decomposition. The results obtained may be summarized as follows:

1. Mature plant materials differ greatly in their base exchange capacity.

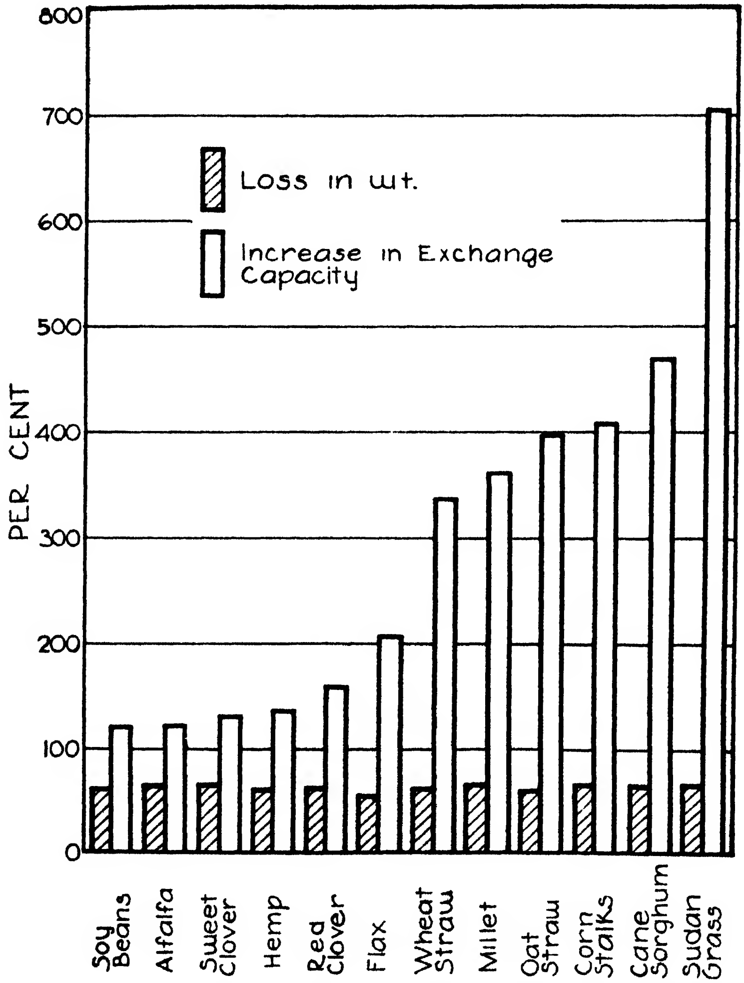

FIG. 6.—Relation between loss in weight and increase in base exchange capacity after 210 days decomposition.

2. The base exchange capacity of 12 plant materials was significantly correlated with their lignin contents, and highly significantly correlated with their nitrogen contents.

3. No correlation was found between the base exchange capacities and either the carbon contents, acid-hydrolyzable fractions, or the alcohol-benzene-soluble materials of the plants.

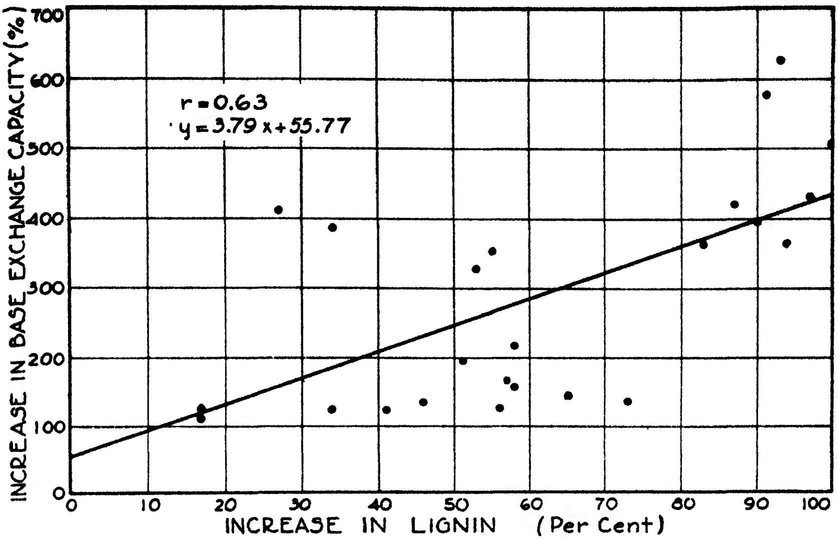

FIG. 7.—Relation between the increase in lignin and the increase in base exchange capacity of plant materials after 210 days of decomposition.

4. As the plant materials decomposed they increased in base exchange capacity many times more than they decreased in weight or in lignin content.

5. The base exchange capacity of the materials was not found to be in the same relation to one another as they decomposed.

6. The lignin content of the plant materials disappeared at the rate of from 24.71% in 210 days with one sample of cane sorghum to 54.80% in 210 days with one sample of soybeans.

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NOTE

ROOTSPROUTS AS A MEANS OF VEGETATIVE REPRODUCTION IN *OPUNTIA POLYACANTHA*

THE habit of reproduction of *Opuntia polyacantha* Haw. by rootsprouts first came to the attention of the writer while engaged in work of cactus eradication for pasture improvement on the ranges of eastern Colorado. The first plants examined were found in a pasture located 5 miles east of Ellicott, Colo. Since then, several other specimens have been examined from other localities around Colorado Springs, Colo.

The heavy invasion of *O. polyacantha* on range pastures of eastern Colorado, where it often forms as high as 40% of the vegetative cover, is greatly accelerated by the rootsprout method of reproduction. The root systems of the plants examined disclosed two definite types of roots, *viz.* (1) a comparatively small type of lateral root which is rather succulent and with numerous ramifications, and (2) a larger type of main lateral which is of a woody nature and not so extensively ramified. The main laterals are coarse in appearance and are covered with a papery surface which flakes off readily. Fig. 1 shows the two types of roots.

FIG. 1.—Root system of *O. polyacantha* showing two types of roots.

The main laterals which separate from the parent plant run to varied lengths close to the surface of the ground. Occasional sublaterals are produced which are also capable of plant development. The longest main lateral recorded extended to a distance of 1.6 meters and had three plant-bearing sublaterals of lengths ranging from 2.5 to 5 decimeters or more. One sublateral had an additional subdivision bearing a new plant.

From the main laterals and its subdivisions young plants are borne which show the initial development from minute areolae with a compact cluster of fine glochids. There is apparently no definite location for these new outgrowths, some main laterals having as many as 10 new plants within a root length of a few decimeters (Fig. 2).

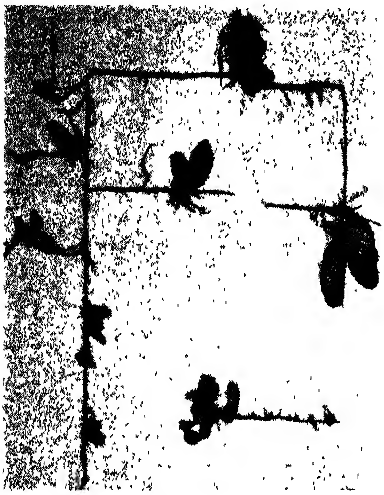

FIG. 2.—Root system of *O. polyacantha* showing distribution of main laterals and frequency of new plant growth.

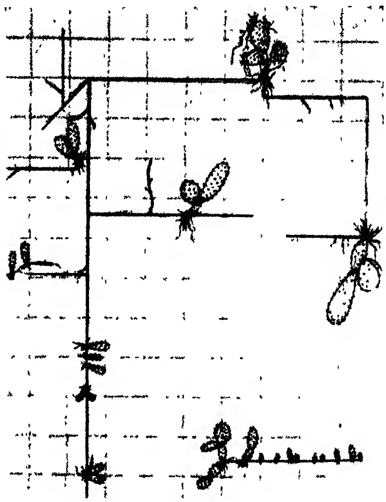

FIG. 3.—Diagrammatic sketch of Fig. 2, showing the distribution to scale 1 large square equals 1 decimeter square.

From Fig. 3, which is a diagrammatic sketch of Fig. 2, a fair conception can be had of the size and distribution of the main laterals and of the frequency of new plant development from the roots of *O. polyacantha*.—A. D. HARVEY, *Soil Conservation Service, Colorado Springs, Colo.*

BOOK REVIEWS

PEDOLOGY

By Jacob S. Joffe, with an introduction by the late Curtis F. Marbut. New Brunswick, New Jersey: Rutgers University Press. XIII + 575 pages, illus. 1936. $5.25.

THE reviewer of this book approaches his task with considerable hesitancy. He feels that only Dr. Joffe with his fortunate combination of a thorough knowledge of soils and of the Russian language could have written such a book, and further that only a very broad and thorough student of the new science of pedology, such as the late Dr. Marbut, could adequately review it. It is very fortunate, therefore, that the latter wrote a quite comprehensive introduction to the volume which serves admirably both as an introduction and as an appraisal of its value to students of soils.

The book is certainly the most voluminous and comprehensive work which has yet appeared in English presenting the viewpoint of the Dokuchaev school of Russian soil workers in the new science of pedology or the science of soils and soil development. Although some of the fundamentals of the new science were known and developed by the Russians some 50 years ago, Marbut points out in his introduction that the new viewpoint of soils as natural dynamic bodies has not yet interpenetrated American soil science nor found its way extensively into our textbooks. He ways, "Soils are almost universally looked upon in the United States as producers of crops", but "this volume is not a discussion of soil productivity" but rather a presentation of the subject of soil derivation and development as a "culture subject".

It may perhaps be a question in the minds of some American soil workers to what extent the new concepts constituting the subject matter of pedology will penetrate and re-direct the many researches in numerous branches of soil science. It is interesting and significant, however, that not a few workers in soil chemistry, soil physics, microbiology, and agronomy are already thinking in terms of soil profiles and climatic factors. American soil workers followed the lead of West-Europeans in the development of geological and physico-chemical classifications of soil. That there may have been some definite reasons why western workers missed the new concepts is brought out in a statement by the Russian, Sibirtzev, quoted on page 19.

Along with Marbut some students may not wholly agree with some of the author's explanation, but as the former points out, these controversial points are a very minor factor in the book and of rather theoretical or academic interest.

The volume as a whole borrows very freely from the work of many students in the field of pedology, and herein lies one of its chief values. References are given at the end of each chapter and there are almost a thousand of such throughout the book. Of special value is the fact that the pioneer work as well as much of the best modern work in pedology published mainly in Russian, is here made available, at least in part, to the American student of soils. The text

consists of 16 chapters divided into six on soil genesis or soil-forming processes and the remainder on soil systematics or the characteristics of the various soil types formed by these processes. The last chapter deals with the pedologic features of the soils of the United States.

It is abundantly evident that the book has involved an immense amount of work on the part of the author, and American soil science owes him a real debt of gratitude for presenting under one cover a wealth of material otherwise almost unavailable and uncorrelated. As to the value of the book, the reviewer feels that he may well take his cue from the words of Dr. Marbut that, "No American pedologist nor anyone interested in the manifold branches of soil science can fail to find it valuable". (R. C. C.)

MATHEMATICAL TREATMENT OF THE RESULTS OF AGRICULTURAL AND OTHER EXPERIMENTS

By M. J. Van Uven. Groningen: P. Noordhoff N. V. 309 pages, illus. 1935. Unbound f. 9.50: bound, f 10.50.

THE entire book is in English. In glancing over the pages, no doubt many biologists who use statistical analysis will be apt to decide that the mathematical treatment is too advanced for them; however, a careful study will reveal the fact that anyone who has a working knowledge of algebra thru quadratics and who is well grounded in least squares can understand most of the mathematical treatment. In a very few instances differential calculus, determinants, and the calculus of probabilities are used.

Much of the text consists of mathematical proofs of formulae for errors and adjustment of observations. As the author says, "It is meant for those who wish to know why they apply certain rules, who like to make a rational choice between different methods, who also wish to develop their sense of criticism before adopting the methods recommended . . . . . Although the treatment in the great majority of problems will not offer any technical difficulties, yet some perseverence is required to become familiar with the subject matter. It is anything but romantic and those who are bent on pleasant reading had better leave this book shut."

These statements apply only to the proofs. Throughout the book, the author has given many numerical examples with detailed calculations which illustrate the use of the various formulae and methods. Certainly any investigator who makes a serious effort to apply biometry to his data will be able to understand and enjoy these calculations. The author has introduced many important methods not found in any texts examined by the reviewer. To mention one will suffice to illustrate this point, *viz.*, weights of observation. It is true that most texts discuss this subject briefly but leave the reader feeling that the use of weights of observation is generally an arbitrary process. Dr. Van Uven shows how rational weights can be used which depend on size of plat, etc. Accordingly the formulae are developed with this point in mind and numerical illustrations exemplify their use.

The following list of subjects treated by chapters shows the scope of the book: Choice of the Representative Value: The Arithmetic

Mean and the Mean Error; Adjustment of Non-equivalent Observations; Indirect Observations of One Variable; Adjustment of a Difference; The Sense of Mean Error; Ideal (Errorless) Values and Asymptotically Averaged Values; Adjustment of a Ratio; Rectilinear Adjustment; Adjustment of Observations with Known Errors; Working up a Number of Sets of Observations into a Common Adjusted Result; Adjustment of a Ratio, the Observations themselves being Means with Known Mean Errors; Indirect Observations of Two or more Variables; Adjustments of Yields in Field Experiments, According to Condition of Soil; Irregular Distribution of Fertility; The Method of Direct Difference; Splitting of the Variance; Analysis of Variance; and Adjustment of Direct Conditioned Observations.

The book might be criticized as not giving sufficient attention to the interpretation of results with small populations coupled with tables of probability suitable for small samples. However, it should be welcomed by all research workers who desire to amplify their knowledge and judgment regarding the proper use of certain phases of statistical methods. (F. Z. H.)

AN OUTLINE OF BIOMETRIC ANALYSIS

By Alan E. Treloar. Minneapolis: Burgess Pub. Co. 193 pages, illus. Mimeoprint; flexible covers. 1936. $3.10.

THE first edition which constitutes Part I of the present edition appeared in 1935 and was reviewed in this JOURNAL (Vol. 27, page 776) so the review of the 1936 edition will be confined largely to the additional material included. The number of pages in the latter is treble that of the former. Part II, comprising 58 pages, is devoted to correlation analysis and includes total, partial, multiple and intraclass correlation; also, the correlation ratio, curvilinear regression, coefficient of contingency, correlation from ($2xm$) fold tables, and correlation between ranks. Part III, comprising 54 pages, is entitled, "The Interpretation of Statistics with Special References to Small Samples". Among the distributions discussed are means, differences between means, s^2, s, Fisher's z, Student's Z (or t) and the joint distribution of $\bar{x}$ and s. Other subjects covered are the analysis of variance and the distributions of correlation coefficients. An appendix of tables includes the following: Table for estimating σ from s, table of critical points in F, probability table of t and the "normal" curve, and a table of z_r in terms of r. A summary of formulae and an index completes the volume.

The term "outline", unqualified, is apt to be misleading. The title would be more definite if it were given as a "comprehensive outline" or "summary of biometrical analysis". The author has brought between the covers a wealth of biometrical information and has included a large number of mathematical formulae with examples of applications. The treatment is largely by use of such formulae and the only objection that might be raised to the manner of presentation is that insufficient numerical examples, worked out in detail, are not included to assist the average biological worker in grasping the methods of calculation. For this reason the work is adapted more to course work in colleges and universities or to biologists who have had some

ground work in the subject. However, the work is excellently written and the choice of material shows good judgment. The reviewer knows of no other work where such a wide scope of biometry is covered with the same detail of mathematical analysis in a single volume. A considerable amount of the mathematics has appeared previously only in statistical journals, references to which are given thruout the book.

About the only subjects entirely omitted are least squares, curve tracing, and a discussion of types of frequency curves and their fitting. This is not a criticism since limitations of space demanded selection and these subjects are treated adequately in other books. The work should be of great value to biologists and students of biometry. The mimeotyping is well done. (F. Z. H.)

METHODS OF STATISTICAL ANALYSIS

By C. H. Goulden. Mineapolis: Burgess Pub. Co. 165 pages, illus. Mimeoprint; flexible covers. 1936. $3.

THIS excellent work might well be entitled a commentary to Fisher's Statistical Methods. The author states "another and perhaps more important reason for the publication of this book is to fill a growing need for the presentation under one cover of a series of examples of the methods recently developed by Dr. R. A. Fisher and his associates".

It is sufficient to say that the author has succeeded admirably in showing those, not familiar with these methods, how the latter should be applied in planning experiments and in analysis of the data; however, the work begins with various fundamental concepts of statistics. Sufficient algebraic formulae are presented to guide the worker in an understanding of the mathematical treatment given in much of the literature, but throughout this has been subordinated to arithmetical examples in the applications of the theory to practical problems. The data have been drawn from many different fields of research. Numerous references to literature and many exercises are given. For these reasons the work should prove of great value as a text book as well as a guide for the biologist whose knowledge of mathematics is somewhat limited, and especially to those who desire to become better acquainted with the newer methods which have stimulated great interest but which have, unfortunately proved difficult for many. The user of this book should be able, easily, to obtain a grasp of these methods and for this reason the work should be welcomed by all experimentalists who desire this accomplishment.

In order that the reader may have an idea of the scope of the book a list of the contents are given, as follows: Frequency Tables—Mean and Standard Deviation, The Normal Frequency Distribution, Tests of Significance with Small Samples, The Correlation Coefficient, Linear Regression, Partial and Multiple Correlation, The X^2 Test for Goodness of Fit and Independence or Association, Tests of Goodness of Fit and Independence with Small Samples, The Analysis of Variance, The Field Plot Test, The Analysis of Variance Applied to Linear Regression Formulae, Non-linear Regression, The Analysis of Covariance, Miscellaneous Applications, a table of values of F and t, and an index. (F. Z. H.)

AGRONOMIC AFFAIRS

EFFECT OF DROUTH ON TREES

THE 1936 drouth is one of the most serious and widespread the nation has ever experienced. In forestry and plant ecology, drouths are of considerable significance because of their effects on survival, growth, and behavior of trees and shrubs. Some species or individuals may be killed, others suffer severe injury, while still others may show remarkable ability to withstand the most adverse conditions. In times of severe drouth, forest plantations suffer severely especially those composed of species not native to the locality or those badly abused as by grazing. In addition many native species that have been slowly invading drier sites or localities may be eliminated over large areas.

As information on drouth resistance of trees and shrubs is sadly lacking, the present affords an unusual opportunity to obtain data of outstanding value. Consequently, it is hoped that those who are in a position to do so will take notes on the reaction of various plants to the drouth. Such information is not alone of scientific interest but has great practical value in many current operations such as the reforestation program of the CCC, cultural operations in the forest, erosion and flood control, etc.

The Forest Service is undertaking the collection of data on the drouth damage. In this it is seeking the aid of botanists, agronomists, foresters, meteorologists, and other interested individuals throughout the drouth area. Consequently, anyone with observations on species behavior should communicate them to the Division of Silvics of the Forest Service at Washington, D. C. Data are desired especially on such features as the nature, extent, and character of the damage, the relative resistance of trees growing on different sites, the comparative ability of native and exotic trees to withstand drouth, and the nature and extent of the damage to stands or to shade or ornamental trees, shrubs, etc. A questionnaire covering these points has been drawn up to aid observers in reporting the effects of the current drouth.

THE FOURTH INTERNATIONAL GRASSLAND CONGRESS

A PRELIMINARY notice of the Fourth International Grassland Congress to be held in Great Britain in July 1937 has been received. Professor R. G. Stapledon, Director of the Welsh Plant Breeding Station and of the Imperial Bureau of Plant Genetics at Aberystwyth, will serve as President of the Congress.

According to present plans, the plenary sessions and sectional meetings of the Congress will be held at Aberystwyth and will be preceeded and followed by tours of centers of grassland interest. The main papers will be by invitation and will be presented at the plenary sessions. Additional papers may be presented before the sectional meetings, but it is desired that intention to present a paper, together with its title and the language in which it will be presented, be communicated to the joint secretaries of the Congress at the earliest possible date.

It is proposed to classify the papers about as follows: (1) Ecology and Pasture Management (including erosion control); (2) Seed Mixtures and Legumes for Use in Poor Pastures; (3) Plant Breeding, Genetics, and Seed Production; (4) Manures and Fertilizers; (5) Fodder Conservation; and (6) Grassland Economics.

For more detailed information about the Congress and the program, address inquiries to the Joint Secretaries, Fourth International Grassland Congress, Agricultural Buildings, Aberystwyth, Great Britain.

SUMMARIES OF PROGRAM PAPERS

IN an effort to anticipate requests from the various national news agencies and special science writers in Washington for releases pertaining to the papers presented before the annual meetings of the Society and of the American Soil Survey Association in November, the Editor of the JOURNAL is requesting all program leaders, through the two Section chairmen, to obtain brief summaries of all papers to be given on the several programs. These summaries should be in the Editor's hands not later than October 15.

PROGRAM FOR THE CROPS SECTION

THE skeleton program for the Crops Section as arranged for the annual meeting of the Society at Washington in November is given below. Members planning to present papers are urged to communicate their intentions to Prof H. B. Sprague, New Jersey Experiment Station, New Brunswick, N. J., by October 15. The title of the paper, a brief summary, and the length of time required for presentation must be at hand by that date to permit announcement to news agencies prior to the meetings. Kindly forward these either to Professor Sprague or to Editor J. D. Luckett at the New York State Experiment Station, Geneva, N. Y. The tentative outline for the program of the Crops Section follows.

WEDNESDAY MORNING

1. Papers on genetics and cytology of crop plants.
2. Papers on all phases of soybean production and utilization.

WEDNESDAY AFTERNOON

1. Papers on physiology and nutrition of crop plants.
2. Roundtable discussion on clover breeding, seed production, and culture (white, alsike, red, and sweet clover).

THURSDAY MORNING

General program of the Society.

THURSDAY AFTERNOON

1:30 to 4 P. M.: 1. Papers on breeding crop plants.
2. Papers on crops teaching and extension.

4 P. M.: Business meeting of the Crops Section.

FRIDAY MORNING

1. Joint symposium with Soils Section on "Newer Developments in Design of Field Experiments."
2. Plant cover in relation to erosion.
3. Miscellaneous papers.

FRIDAY AFTERNOON

1. Papers on southern field crops.
2. Miscellaneous papers.

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CARBOHYDRATE CONTENT OF COTTON PLANTS AT DIFFERENT GROWTH PERIODS AND THE INFLUENCE OF FERTILIZERS[1]

D. R. ERGLE[2]

THE results reported in this paper showing the carbohydrate content of cotton plants in the growing season were secured in a broad study of soil fertility and fertilizer problems on the blackland soils of Texas and the possible relation of added plant food and cultural practices to the root-rot of cotton, which prevails on many soils of this belt. The results here reported are confined to the carbohydrate changes at different periods of the development of the cotton plant and the effect of fertilizer applications on the carbohydrate composition.

Studies by Mason and Maskell (6, 7)[3] and by Phillis and Mason (9) on the transport and polar distribution of carbohydrates are distinct contributions to the knowledge of carbohydrate metabolism in the cotton plant; as is also the work of Caskey and Gallup (2) on the developing cotton boll which has given important data on the changes in the sugar content of the boll parts. In the work reported in this paper periodic changes in concentration of certain carbohydrate fractions of the cotton plant and the effect of fertilizers on these concentrations were determined from the time of emergence of the seedling from the soil to the time of the first picking. The subject is a complex one and the results are given as a progress report, as they throw some light on the metabolism of the cotton plant as influenced by added plant food in this soil.

PLAN OF EXPERIMENT

The cotton plants used in these studies were grown on Wilson clay loam soil, near Elgin, Texas, which is one of a series of experiments planned to study the

[1]Contribution from the Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Plans for these studies were developed with the author by P. R. Dawson, then in charge of the Soil Fertility Cotton Root-rot Investigations at Austin, Texas, and were carried out under the direction of J. E. Adams, now in charge at Austin, Texas. The work was under the general supervision of J. J. Skinner, in charge of cotton soil and fertilizer investigations. Received for publication June 5, 1936.

[2]Assistant chemist.

[3]Numbers in parenthesis refer to "Literature Cited", p. 786.

effect of added plant food upon the maturity and yield of cotton. The electrodialysis constituents of the cotton plants in this experiment were also determined periodically and the results reported by Collins and Rigler (3) elsewhere. Each of the following fertilizer treatments was used and was replicated five times: 0-15-0, 3-9-3, 9-3-3, and 15-0-0.[4] A check or untreated plat was included. The distribution of the plats was in accordance with the randomized-block method according to Fisher (5). Fertilizers containing 15% total plant food were applied at the rate of 900 pounds per acre simultaneously with the planting of the experiments to cotton. One-half of the total nitrogen in the fertilizer was supplied by ammonium sulfate and one-half by sodium nitrate. The source of phosphorus was superphosphate and the source of potash was potassium sulfate.

Representative samples of cotton plants were collected at 1 o'clock on Tuesday of each week. Plants from each of the replicated plats were composited for the chemical work. The first date of sampling was April 29, 1935, corresponding to the seedling stage, and the last date, August 20, 1935, corresponding to approximate boll maturity. The number of plants collected on each date of sampling was determined to a great extent by their size. On the first date of sampling, a total of 100 seedlings was collected for each treatment, while on the last date of sampling, only 8 to 10 plants were collected to represent each treatment. When choosing the plants for sample material representative ones were selected based on their height and the number of nodes, squares, flowers, and bolls they contained.

Between April 29 and May 21 the whole plant, including tops and roots, was analyzed. After May 21, 1935, the plants were separated into tops and roots and throughout the analysis were treated as separate samples. The plant material was ground in a food chopper, mixed, and weighed aliquots removed for analysis and moisture determinations. For analysis, 150 to 200-gram portions of top material and 50 to 100-gram portions of root material were killed by boiling for 30 minutes in alcohol, the concentration being kept above 80%.

In general, the methods of the Association of Official Agricultural Chemists were used, as indicated below.

Moisture.—The samples for moisture determinations were heated at 65° C to a constant weight in an electric oven equipped with mechanical connection. The loss in weight was expressed as percentage of the original green weight.

Sugars.—Shortly after killing, the plant material was filtered from the alcohol, dried, ground, and extracted in a Soxhlet extractor with boiling 80% alcohol to remove the sugars. The alcohol extract was combined with the alcohol from killing and adjusted to a definite volume. A suitable aliquot of the alcohol solution was prepared for analysis (1, page 112 [37, b]). An aliquot of the resulting cleared and deleaded solution was analyzed for reducing sugars. The cuprous oxide, using Fehling's Soxhlet solution, was precipitated according to the method of Munson and Walker (1, page 379 [38]), and determined by the cuprous titration method of Schaffer and Hartmann (10). The sugar equivalent is expressed as percentage anhydrous dextrose in green weight of plant material. The reducing sugars are designated monoses. For the determination of total sugars a second aliquot of the cleared solution was inverted with hydrochloric acid at room temperature according to the official method (1, page 373 [23,c]), and its reducing power determined. The difference between the values for total sugars and reducing sugars represents dioses, or non-reducing sugars. All were expressed in terms of a common unit, i. e., percentage anhydrous dextrose in fresh plant material.

[4]Fertilizer ratios are given in the order, $N-P_2O_5-K_2O$.

Polysaccharoses.—The entire residue from the extraction of sugars was dried to a constant weight at 65° C, and the weight recorded for use in calculating the polysaccharoses to the green weight basis. An aliquot of 3.5 to 4.0 grams of the oven-dried, alcohol-extracted plant tops and a 2.5 to 3.0-gram aliquot in the case of root materials, was hydrolyzed with hydrochloric acid (1, page 282 [23]). Reducing sugars were determined on an aliquot of the cleared and deleaded hydrolysate and expressed as percentage anhydrous dextrose in fresh plant material. To convert the weight of oven dried, alcohol-extracted residue to a comparable green weight basis, a ratio of green weight to weight of alcohol-extracted residue was used.

Total carbohydrates.—The percentage total carbohydrates was calculated from the sum of the values for total sugars and acid-hydrolyzable polysaccharoses.

RESULTS

CHANGES IN CONCENTRATIONS OF SUGARS

The analytical data are presented in Table 1 and in Fig. 1. The data are arranged to show (a) the normal weekly variations in concentration of the carbohydrate fractions during plant growth, and (b) the effect of fertilizers on the concentration of the carbohydrates in the plants. Due to rains, samples could not be collected on May 14, May 28, and June 18, and samples were not taken from the plat treated with a 9–3–3 fertilizer on April 29 and May 7.

For convenience in interpreting the analytical results, the growth period of the cotton plant was divided into four important stages, namely, (a) seedling, (b) square formation, (c) boll formation, and (d) boll maturity, the latter being open bolls ready for harvest.

The monoses, dioses, and total sugars in the tops of the untreated cotton plants, as given in Fig. 1A, show considerable fluctuation throughout the entire period of plant development. The decrease in concentration of total sugars between the seedling stage and early square formation may be explained by rapid longitudinal plant growth. When the plant entered the square formation period, the concentration of the total sugars began an upward trend which increased with great rapidity during the early stage of boll formation. Excepting one sharp decrease in concentration which occurred between July 9 and July 23, the concentration of total sugars continued to increase until some of the bolls had opened, after which the concentration began to decrease. The monose sugars started decreasing when the bolls were about ready to open and continued to decrease throughout the remainder of the time samples were collected. The diose sugars did not begin decreasing until after the opening of cotton had commenced.

The increase in concentration of the total sugars in the cotton plant during boll formation is thought to have been due to the demand of the bolls for soluble carbohydrates necessary for the formation of the cotton lint and insoluble carbohydrate generally. The decrease, after the maturity of most of the bolls, may be explained as due in part to the transformation of the soluble carbohydrates into the cellulose of the bolls and their content of cotton and into storage carbohydrates. Caskey and Gallup (2) reported data which

TABLE 1.—*Carbohydrate content of cotton plants grown on Wilson clay loam near Elgin,*

Date, 1935	Plant part	Fertilizer treatment*									
		0:15:0			3:9:3			9:3:3			
		Mon-oses %	Di-oses %	Total %	Mon-oses %	Di-oses %	Total %	Mon-oses %	Di-oses %	Total %	Mon-oses %
April 29	Whole plant	0.492	0.222	0.714	0.310	0.190	0.500	—	—	—	0.292
May 7	Whole plant	0.230	0.383	0.613	0.156	0.339	0.495	—	—	—	0.253
May 21	Whole plant	0.063	0.200	0.263	0.081	0.239	0.320	0.078	0.304	0.328	0.063
June 4	Whole plant	0.252	0.410	0.622	0.222	0.448	0.670	0.285	0.331	0.616	0.232
	Root	0.193	1.517	1.710	0.234	1.733	1.967	0.249	1.644	1.893	0.266
	Top	0.257	0.294	0.551	0.221	0.327	0.548	0.289	0.194	0.483	0.229
June 11	Whole plant	0.239	0.367	0.606	0.354	0.317	0.671	0.261	0.342	0.603	0.147
	Root	0.678	0.850	1.528	0.346	1.654	2.000	0.397	1.660	2.057	0.190
	Top	0.187	0.311	0.498	0.355	0.171	0.526	0.245	0.187	0.432	0.143
June 25	Whole plant	0.312	0.386	0.698	0.390	0.461	0.851	0.385	0.456	0.841	0.299
	Root	0.354	1.171	1.525	0.364	1.286	1.650	0.324	1.386	1.710	0.274
	Top	0.307	0.285	0.592	0.392	0.368	0.760	0.392	0.342	0.734	0.303
July 2	Whole plant	0.339	0.643	0.982	0.590	0.575	1.165	0.514	0.629	1.143	0.353
	Root	0.377	2.038	2.415	0.548	1.887	2.435	0.495	1.985	2.480	0.434
	Top	0.336	0.504	0.840	0.595	0.432	1.027	0.514	0.513	1.027	0.345
July 9	Whole plant	0.753	0.675	1.428	,0810	0.982	1.792	0.685	0.895	1.580	0.548
	Root	0.471	2.209	2.680	0.524	2.516	3.040	0.510	2.450	2.960	0.454
	Top	0.779	0 536	1.315	0.837	0.838	1.675	0.700	0.753	1.453	0.546
July 16	Whole plant	0.571	0.839	1.410	0.888	0.899	1.787	0.733	0.960	1.693	0.552
	Root	0.488	2.207	2.695	0.600	2.322	2.922	0.570	2.494	3.064	0.454
	Top	0.586	0.687	1.273	0.914	0.759	1.673	0.801	0.752	1.553	0.561
July 23	Whole plant	0.916	0.629	1.547	1.003	0.745	1.748	0.784	0.739	1.523	0.499
	Root	0.539	1.921	2.460	0.570	2.218	2.788	0.534	1.916	2.450	0.424
	Top	0.950	0.517	1.467	1.043	0.624	1.667	0.944	0.502	1.446	0.506
July 30	Whole plant	1.178	0.556	1.734	1.048	0.526	1.574	0.993	0.792	1.785	0.840
	Root	0.464	1.888	2.352	0.570	2.450	3.020	0.500	2.295	2.795	0.448
	Top	1.230	0.463	1.693	1.070	0.443	1.513	1.027	0.683	1.710	0.875
Aug. 6	Whole plant	0.800	0.621	1.421	0.845	0.640	1.485	0.816	0.702	1.518	0.725
	Root	0.572	1.782	2.354	0.624	2.489	3.113	0.592	2.531	3.123	0.540
	Top	0.820	0.533	1.353	0.858	0.555	1.413	0.828	0.588	1.416	0.737
Aug. 13	Whole plant	0.694	0.782	1.476	0.740	0.902	1.642	0.630	0.835	1.465	0.710
	Root	0.526	2.174	2.700	0.580	2.230	2.810	0.554	2.526	3.080	0.426
	Top	0.706	0.671	1.377	0.752	0.788	1.540	0.636	0.726	1.362	0.735
Aug. 20	Whole plant	0.384	0.914	1.298	0.439	1.008	1.447	0.293	0.999	1.292	0.441
	Root	0.474	2.141	2.615	0.574	2.666	3.240	0.430	2.560	2.990	0.466
	Top	0.377	0.806	1.183	0.425	0.848	1.273	0.281	0.854	1.135	0.438
Average†	Whole plant	0.585	0.617	1.202	0.666	0.682	1.348	0.580	0.698	1.278	0.485
	Root	0.467	1.809	2.276	0.503	2.132	2.635	0.469	2.132	2.600	0.398
	Top	0.594	0.510	1.104	0.678	0.560	1.238	0.605	0.554	1.159	0.493

*Fertilizer ratios are given in the order N—P_2O_5—K_2O.
†Averages are calculated on data from June 4 to August 20, inclusive.

showed a gradual decrease in the sugar content of all parts (seed, lint, and burs) of the boll during a 30-day period of growth.

Some noticeable differences were found between the course of the changes in sugar concentrations in the plant tops and those in the roots during plant development, as seen in Fig. 1A and B. A sharp decrease between June 4 and June 25 in case of the roots corresponds to a slight increase in the plant tops. This was a period preceding

Texas, as influenced by fertilizer treatment and stage of growth (percentage of green weight).

					Polysaccharoses for fertilizer treatment					Total carbohydrates for fertilizer treatment				
15:0:0		Check			0:15:0	3:9:3	9:3:3	15:0:0	Check	0:15:0	3:9:3	9:3:3	15:0:0	Check
Di-oses %	Total %	Mon-oses %	Di-oses %	Total %	%	%	%	%	%	%	%	%	%	%
0.199	0.491	0.586	0.245	0.831	1.57	1.47	—	1.68	1.54	2.28	1.97	—	2.17	2.37
0.399	0.652	0.180	0.406	0.586	1.93	1.20	—	1.82	1.85	2.54	1.70	—	2.47	2.44
0.279	0.342	0.073	0.288	0.361	—	1.52	—	2.21	1.78	—	1.84	—	2.55	2.24
0.514	0.746	0.164	0.390	0.554	2.77	2.52	2.82	3.30	3.49	3.39	3.19	3.44	4.05	4.04
1.949	2.215	0.218	1.877	2.095	2.80	2.36	2.46	2.67	2.65	4.51	4.33	4.35	4.89	4.75
0.374	0.603	0.159	0.242	0.401	2.76	2.54	2.86	3.36	3.57	3.31	3.09	3.34	3.96	3.97
0.425	0.572	0.250	0.360	0.610	2.94	2.81	2.87	3.26	3.21	3.55	3.48	3.47	3.83	3.82
1.396	1.586	0.235	1.394	1.629	3.12	3.25	3.02	3.25	3.58	4.65	5.25	5.08	4.84	5.21
0.319	0.462	0.252	0.231	0.483	2.92	2.76	2.86	3.26	3.17	3.42	3.29	3.29	3.72	3.65
0.205	0.504	0.205	0.394	0.599	3.45	3.20	3.03	3.42	3.62	4.15	4.05	3.87	3.92	4.22
1.456	1.730	0.314	1.128	1.442	3.65	3.73	3.94	3.73	3.93	5.18	5.38	5.65	5.46	5.37
0.070	0.373	0.190	0.293	0.483	3.42	3.13	2.92	3.40	3.57	4.01	3.89	3.65	3.77	4.05
0.720	1.053	0.327	0.671	0.998	4.03	4.00	3.60	3.63	3.98	5.01	5.17	4.74	4.68	4.98
2.136	2.570	0.340	1.746	2.086	5.34	5.78	5.55	4.62	4.96	7.76	8.22	8.51	7.19	7.05
0.573	0.918	0.325	0.545	0.870	3.90	3.81	3.42	3.52	3.87	4.74	4.84	4.45	4.44	4.74
1.045	1.593	0.596	0.819	1.415	5.13	4.96	5.08	4.65	5.13	6.56	6.75	6.66	6.24	6.55
2.436	2.890	0.518	2.642	3.160	8.82	9.82	9.46	8.27	8.62	11.50	12.86	12.42	11.16	11.78
0.917	1.463	0.601	0.645	1.246	4.79	4.50	4.68	4.29	4.79	6.11	6.18	6.13	5.75	6.04
0.703	1.255	0.475	0.833	1.308	5.10	6.00	5.66	4.84	5.19	6.51	7.79	7.35	6.10	6.50
1.690	2.144	0.457	2.171	2.628	10.36	13.78	12.60	9.02	11.33	13.06	16.70	15.66	11.16	13.96
0.615	1.176	0.477	0.670	1.147	4.54	5.28	4.93	4.47	4.44	5.81	6.95	6.48	5.65	5.59
0.594	1.093	0.545	0.545	1.090	5.34	5.24	5.76	4.13	4.70	6.89	6.99	7.28	5.22	5.79
1.819	2.243	0.416	1.944	2.360	9.98	11.97	13.68	8.15	9.46	12.44	14.76	16.13	10.39	11.82
0.486	0.992	0.557	0.407	0.964	4.93	4.68	5.12	3.78	4.22	6.40	6.35	6.57	4.77	5.18
0.733	1.573	0.792	0.595	1.387	5.39	5.95	6.32	5.33	5.18	7.12	7.52	8.11	6.90	6.57
2.106	2.554	0.492	2.032	2.524	12.33	15.88	17.27	13.23	13.05	14.68	18.90	20.07	15.78	15.57
0.625	1.500	0.821	0.456	1.277	4.93	5.52	5.56	4.70	4.43	6.62	7.03	7.27	6.20	5.71
0.738	1.463	0.769	0.618	1.387	5.86	5.96	6.26	5.26	5.21	7.28	7.45	7.78	6.72	6.60
2.150	2.690	0.486	1.718	2.204	15.27	15.13	18.36	13.47	14.12	17.62	18.24	21.48	16.16	16.32
0.643	1.380	0.784	0.553	1.337	5.06	5.55	5.48	4.73	4.71	6.41	6.96	6.90	6.11	6.05
0.858	1.568	0.720	0.947	1.667	5.70	6.55	6.24	5.86	6.81	7.18	8.19	7.71	7.43	8.48
2.314	2.740	0.504	1.984	2.488	13.77	15.45	16.42	15.12	16.08	16.47	18.26	19.50	17.86	18.57
0.738	1.473	0.740	0.840	1.580	5.06	5.80	5.62	5.08	5.90	6.44	7.34	6.98	6.55	7.48
0.914	1.355	0.408	0.842	1.250	6.28	7.14	7.20	5.84	6.82	7.58	8.59	8.49	7.20	8.07
2.214	2.680	0.444	2.356	2.800	14.75	17.99	16.89	15.48	17.63	17.37	21.03	19.88	18.16	20.43
0.802	1.240	0.404	0.698	1.102	5.59	6.15	6.32	5.00	5.79	6.77	7.42	7.46	6.24	6.89
0.676	1.161	0.477	0.638	1.115	4.73	4.94	4.99	4.50	4.85	5.93	6.29	6.26	5.66	5.96
1.969	2.367	0.402	1.908	2.310	9.11	10.45	10.88	8.82	9.58	11.39	13.08	13.52	11.19	11.89
0.560	1.053	0.483	0.507	0.990	4.35	4.52	4.52	4.14	4.41	5.46	5.76	5.68	5.20	5.40

active boll formation, and this decrease in concentration of sugars in the roots was possibly due in part to withdrawal of carbohydrates to aid in meeting the demand by the bolls. Another marked difference occurred at the end of the season. While the total sugars in the plant top indicated a downward trend, the total sugars of the roots, during the same time, indicated an upward trend in concentration. It seems that with no further demand for soluble carbohydrates by the top of the plant, the synthesized carbohydrates were being stored in the roots.

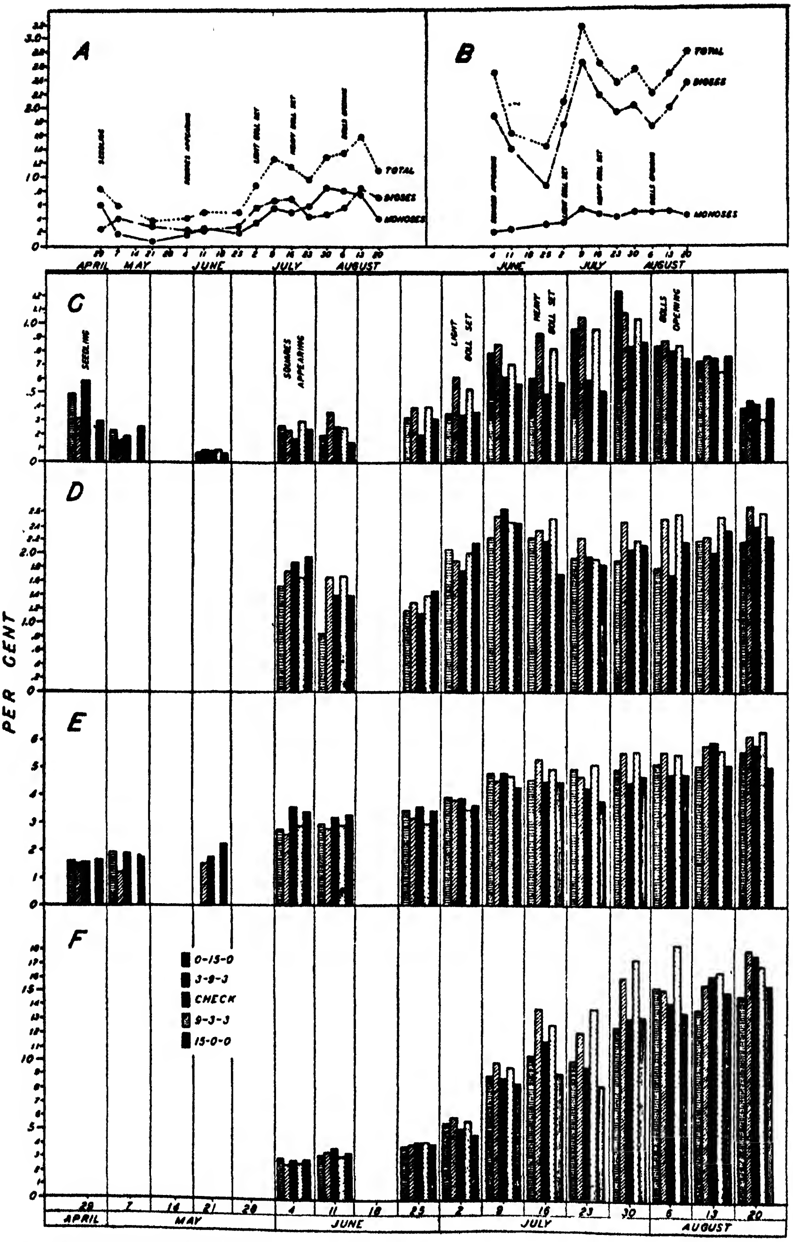

FIG. 1.—Periodic change in carbohydrate constituents of cotton plants grown on Wilson clay loam soil, and the effects of fertilizers containing different proportions of nitrogen and phosphorus. Carbohydrate content expressed as percentage of anhydrous dextrose in green plants. A, monose, diose, and total sugar content of tops of plants grown on unfertilized soil; B, monose, diose, and total sugar content of roots from plants grown without fertilizer; C, effect of fertilizers on monose sugar content of plant tops; D, effect of fertilizers on diose sugar content of roots; E, effect of fertilizers on polysaccharose content of plant tops; F, effects of fertilizers on polysaccharose content of roots.

The diose sugars in the roots greatly exceeded in concentration the monose sugars, as shown in Fig. 1B. The diose sugars exhibited sharp fluctuation, corresponding to morphological changes in the tops of the cotton plant, while the monose sugars, though exhibiting a similar change, do not fluctuate as greatly. Therefore, the diose sugars are perhaps a better index of carbohydrate changes in the root than are the monose sugars. The concentrations of diose and total sugars in the roots exceeded those found in the tops of the cotton plant. On the other hand, using an average figure computed from data covering the same period of growth, June 4 to August 20, the concentration of monoses in the tops slightly exceeds the concentration of monoses in the roots of unfertilized plants. In the case of plants grown on fertilized plats this difference, though greater, was similar, as seen from the data in Table 1.

Fig. 1 C depicts the effects of fertilizers on monose sugar concentrations in the tops of the developing cotton plant. During the early stages of plant development there were no consistent effects of the fertilizers on the monoses in the plant tops as judged by their percentage concentrations. After square formation commenced, the tops of plants with fertilizers 3–9–3 and 9–3–3 showed a higher level of monose sugars than did those from the corresponding unfertilized plats, and this higher level was maintained throughout the period of boll formation and development. After boll maturity as judged by opening, there was little or no difference in this respect between plants from fertilized and unfertilized plats. A fertilizer containing only phosphorus increased the monoses above those in the check only after boll formation started, and from there on behaved somewhat similarly to fertilizers 3–9–3 and 9–3–3. Nitrogen alone did not seem to affect consistently the monose concentration in the tops of the cotton plant during any of the stages of growth as compared with the concentration of monoses measured in the tops of plants from unfertilized plats.

In general, the effects of fertilizers on the diose sugars of the cotton root were not as pronounced as were the effects on the monose sugars of the plant top, as seen by comparing Fig. 1 C and D. Fertilizer ratios 3–9–3 and 9–3–3 increased the concentration of diose sugars in the roots, but the consistent increases were limited to the latter part of the season at the time of late boll formation and boll maturity. Neither nitrogen nor phosphorus alone seemed to have any consistent effect upon the sugar content of the root as judged by the dioses.

CHANGES IN CONCENTRATION OF POLYSACCHAROSES

The acid-hydrolyzable, polysaccharoses, representing the storage and insoluble carbohydrates, were found to constitute, on the average, approximately 80% of the total carbohydrates in both the root and top portions of the cotton plant. Due to their preponderance the trends of concentration of polysaccharoses in the plants were found to be in keeping with the total carbohydrates.

The trend in the storage of carbohydrates in the tops of the cotton plant was upward during most of the season, as shown in Fig. 1 E.

During the early stages of plant development, in general, all fertilizers tended to reduce the storage of carbohydrates in comparison to the concentration measured in plant tops from unfertilized plats. Late in the season, however, at the period of late boll formation and boll maturity, fertilizers 3–9–3 and 9–3–3 led to increased storage of carbohydrates above the check or unfertilized plants. This was probably a result of the difference in rate of growth and size of plants from fertilized and unfertilized plats. Plants from fertilized plats, in growing faster in proportion to their rate of production, apparently were using more carbohydrates than the unfertilized plants, which fact would be reflected in lower concentrations of polysaccharoses. At the end of the growing season, when the demand for carbohydrates was low, those plants possessing greater photosynthetic activity showed a larger accumulation of carbohydrates. The effect of phosphorus alone on the storage of carbohydrates in the tops was similar to that of the complete fertilizers, but of less magnitude. During the late periods nitrogen alone indicated a tendency toward causing the storage of less carbohydrates than the check. This is probably associated with the observed tendency of heavily fertilized plants to remain vegetative a longer period of time than unfertilized plants and those fertilized with phosphorus-containing fertilizers.Crowther (4) made a similar observation and concluded that the main function of nitrogen was to initiate meristematic activity. Musgrave and Coe (8), among others, found that increasing the nitrogen supply tended to cause late maturity of cotton.

The rate and extent of storage of carbohydrates in the roots of the cotton plant, as judged by percentage concentrations of the polysaccharoses, greatly exceeded that for the plant tops, as shown in Fig. 1 E and F. The direction of change in concentration of polysaccharoses in the roots as the cotton plant approached maturity was upward. The period of early boll formation was characterized by a sudden, sharp increase in storage of carbohydrates in the roots.

In general, the effects of fertilizers on the storage of carbohydrates was reflected to a greater degree by the polysaccharoses in the roots than by those in the tops. Plants fertilized with ratios 3–9–3 and 9–3–3 stored more carbohydrates in their roots than did plants from unfertilized plats or fertilized with either nitrogen or phosphorus alone. The largest and perhaps most significant differences occurred during the latter part of the period of boll formation when the demand for carbohydrates by the bolls was low and plant growth had practically ceased. Phosphorus used alone did not show any definite effect, while nitrogen used alone tended to decrease the storage of carbohydrates in the roots as compared to roots from unfertilized plats.

GENERAL DISCUSSION

The effects of the fertilizers used in these experiments on carbohydrates in the cotton plant may best be interpreted through their relation to plant growth, yield, and time of maturity. In Table 2[6]

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[6]The author is indebted to Messrs. H. V. Jordan and J. H. Hunter for their help in acquiring the plant data and for the use of unpublished data on yields for the experimental plats.

TABLE 2.—*Effect of fertilizers on plant growth, boll formation, yield, and carbohydrate content of cotton plants from plats used for analytical studies.*

Fertilizer treatment*	Weight per plant, grams†	Height of plant, inches†	No. of nodes†	No. of squares†	No. of bolls†	Yield of seed cotton per acre, lbs.	Percentage of total yield at first picking	Total carbohydrates in green weight	
								Grams per plant†	Concentration %†
0–15–0...	152	21.6	17.7	6.1	3.5	485	65.6	9.01	5.93
3–9–3.....	177	24.7	17.9	8.1	5.4	665	73.0	11.13	6.29
9–3–3.....	185	23.9	17.8	7.4	5.4	740	69.4	11.58	6.26
15–0–0....	151	19.6	17.0	8.6	3.5	472	53.6	8.55	5.66
Check.....	109	17.8	17.2	4.7	2.8	384	52.2	6.50	5.96

*Fertilizer ratios are given in the order N—P_2O_5—K_2O.
†Averages are calculated on data from June 4 to August 20, inclusive

are recorded the average results from observations made on plants in the experimental plats sampled for analytical materials, and also the average total carbohydrate content calculated as percentage concentration and as actual amount in grams per whole plant. All the fertilizers used increased plant weight, plant height, yield of seed cotton, and maturity, except nitrogen alone which did not increase maturity above that of the check. However, the two complete fertilizers, 3-9-3 and 9-3-3, were by far the most effective in increasing plant growth and yield of cotton and in hastening maturity; and of the two fertilizers, that with the higher proportion of nitrogen, 9-3-3, caused the greater increase in plant weight and yield of cotton. There is good agreement between plant development and yield and the corresponding carbohydrate content in grams per plant.

Two factors possibly influencing considerably the concentration of carbohydrates in the plants at periods during growth are, first, the rate of photosynthesis or production of carbohydrates, and second, the rate of their utilization. A discussion of these in connection with the data given in Table 2 is of interest. A plant may have a relatively higher photosynthetic activity, due to added fertilizers, than another not so treated, but due to more rapid utilization of the synthesized carbohydrates in growth, may show as low or even a lower concentration than plants from the untreated plat. However, at the end of the rapid growth period when the demand for carbohydrates is low, the increased power to produce carbohydrates as a result of favorable fertilizer treatment should exhibit itself for a time in a higher concentration level than is found in the untreated plant.

Fertilizer ratios 3-9-3 and 9-3-3 produced results which are believed to be interpretable from this theoretical standpoint. On the average, the concentration of total carbohydrates in the plants fertilized with these ratios was higher, as shown in Table 2. However, the most significant increase did not occur until the plant was closely approaching maturity, and during the period of active growth the carbohydrate level in the tops of these plants was a little lower than that of the unfertilized plants.

The average value for the concentration of total carbohydrates in plants grown with a fertilizer containing phosphorus alone (0-15-0) does not differ greatly from that for the check. However, an inspection of the plotted data for the soluble and insoluble carbohydrates in the plant tops shows that this fertilizer exhibited a tendency to increase the carbohydrate concentrations above that of the check during the latter stage of plant development.

The average value for the effect of nitrogen alone on the concentration of total carbohydrates is below that for the check, and is in agreement with the trend for the weekly data. Therefore, it appears that while phosphorus increased the actual production of carbohydrates above that of unfertilized plants, as judged by the plant data in Table 2, the utilization of the carbohydrates was such that there was not much difference between the ratio of carbohydrate production to carbohydrate utilization, as shown by the concentration. In the case of the plants fertilized with nitrogen alone, the effect on the concentration of total carbohydrates was more definite than

in the case of phosphorus. Both the average and the individual values show that the tendency of nitrogen was toward maintaining a lower concentration of total carbohydrates than was found in either the unfertilized plants or those fertilized with phosphorus-containing fertilizers. Due to the observed tendency of these plants to remain vegetative for a longer period of time, the period of active carbohydrate production and utilization was probably prolonged. During this time the ratio of carbohydrate production to utilization was low as compared with that of the unfertilized plants and those fertilized with phosphorus-containing fertilizers. This effect would be reflected in a low concentration of carbohydrates, as was actually found.

SUMMARY

The data show that the total sugars, representing the soluble carbohydrates, decreased in concentration in the plant tops between the stages of seedling and square formation, after which the trend in concentration was upward and increased rapidly during active boll formation, the rate of increase diminishing as the bolls approached maturity. At maturity, when the cotton bolls began opening, the total sugars began decreasing in concentration.

Excepting the period of active boll formation, when the concentration of total sugars in both the tops and roots was rapidly increasing, the course of the changes in concentration of the total sugars in the roots tended to be opposite to that in the plant top. During the period of study, the concentration of total sugars in the roots exceeded the concentrations in the plant tops. The diose sugars of the roots exceeded by a large margin the concentration of monose sugars. In the tops of the cotton plant the difference in concentration of the two sugars was influenced by the stage of plant development and the fertilizer used. In general, during the latter stage of boll formation, July 9 to August 6, the monose sugars exceeded in concentration the diose sugars.

The monose sugars in the tops of cotton plants and the diose sugars in the roots were the best indicator of the effects of fertilization on the soluble carbohydrates.

The polysaccharoses, representing the insoluble or storage carbohydrates, were found to occur in greater concentration in the roots than in the tops of the cotton plant. In general, the course of the changes in concentration for both the roots and tops of the plant was upward throughout the growth periods studied. The rate of change in concentration was greater in the plant roots than in the tops.

Plants fertilized with complete fertilizers had a higher level of soluble and insoluble carbohydrates in both the tops and roots during the latter stages of plant development than did the unfertilized plants or those fertilized with nitrogen and phosphorus separately. Phosphorus alone tended towards effecting a higher level in the plant tops. Nitrogen alone had no consistent effect upon the soluble carbohydrates in either the tops or roots but did tend to effect a lower concentration of insoluble carbohydrates near the end of the season.

The growth of cotton plants and yields of seed cotton were increased by fertilizer applications, the largest returns resulting from

the 9-3-3 followed by the 3-9-3 fertilizer. These mixtures also produced most cotton at the first picking, showing an early stimulating effect on growth and square and boll formation, resulting in earlier maturity of cotton. The greater carbohydrate content of the plants correlates with larger plant growth and larger yields. The total carbohydrate content expressed as percentage of green plant or as grams per plant was greatest in plants grown with 9-3-3 and 3-9-3 fertilizers, these being the fertilizers giving largest plant growth and greatest yields.

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PRELIMINARY STUDIES ON THE CARBOHYDRATES IN THE ROOTS OF BINDWEED[1]

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IN the last decade bindweed has increased in prominence in many sections of the country. Because of its rapid spread and its harmful nature, it has established itself as one of the worst weeds in Colorado.

A number of different chemical treatments and cultural practices have been attempted in efforts to control the weed, with varied results. Since clean cultivation has seemed to be the most practical method of control in cases where this plant pest is distributed over large areas, experiments were undertaken to study the carbohydrates in the roots of bindweed which had undergone cultivation at varied intervals throughout the growing season of 1935. The purpose of these experiments was to study the trend of the root carbohydrates of bindweed under control measures in order to obtain some information concerning the effect of cultivation upon the root reserves.

The results reported in these preliminary studies give differences in reducing sugars, sucrose, total sugars, and three polysaccharide fractions, dextrin, starch, and acid-hydrolyzable substances. Further investigation is now under way and general conclusions may be made after a more complete study.

PREVIOUS WORK

The literature on methods of eradicating weeds is voluminous, but information regarding the food reserves is meagre. Particularly is this true of bindweed. An examination of this literature failed to reveal any report of investigations of the root reserves in bindweed under systematic cultivation. Comparable data, however, were found concerning alfalfa and certain other hay and pasture crops.

Salmon, Swanson, and McCampbell (18)[3] found that the reserves deposited in the roots greatly influenced the top growth in alfalfa and that, when these reserves were not replenished between successive cuttings, the amount of root and top growth diminished after each cutting.

Graber, *et al.* (9), working with alfalfa and other hay crops, observed that frequent cuttings at immature stages retarded the root and top growth chiefly because of the failure to elaborate organic foods in excess of the quantities required for growth. The amount of root and top growth and the longevity of the alfalfa plants was generally associated with high carbohydrate and nitrogen content in the roots. Low reserves in the roots caused many of the plants to die before winter or to be killed by winter freezing. They attach significant importance to those organic compounds elaborated in photosynthesis as limiting factors of growth for all perennial herbaceous plants.

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[3]Figures in parenthesis refer to "Literature Cited", p. 797.

Nelson (15), Leukel (11), and Albert (1) found that vigorous top growth in alfalfa is obtained when root reserves are accumulated during the period of successive cuttings and that too frequent cutting at immature stages diminishes the stored reserves and decreases the future development of the roots as well as that of the tops.

Pierre and Bertram (16), working with Kudzu, showed that plants receiving six cuttings per season decreased in weight during a period of 2 years, while those receiving four cuttings increased about 150% and those receiving one cutting increased 1,250%.

It was noted by Crider (8) and Rogers (17) that the roots of weeds make significant growth under conditions which are unfavorable for vegetative growth.

Welton, Morris, and Hartzler (20) reported that the organic food reserves stored in the rootstalks of Canada thistles varied with the season of the year. They observed that the percentage declined during the period of vegetative growth, reaching a minimum about June 1, and then gradually increased until the end of the season. A study was also made upon the organic food reserves in relation to various top-cutting treatments in which they found that mowing delayed the storage of food reserves. The reserves decreased more rapidly with increased frequency of mowing and mowing when the plants were in full bloom apparently had but little effect on the food reserves.

Kennedy and Crafts (10) report that bindweed cannot be controlled by cutting the stems below the surface of the ground because of the large storage capacity of the root and its ability to produce new shoots. They observed that roots taken from a depth of 14 feet were capable of producing new plants. This work was an investigation on the effect of arsenical sprays applied to the foliage. They found that the effectiveness of the spray was dependent upon atmospheric and soil conditions and upon the period of exposure to provide for penetration of the toxin.

In 1930, Crafts and Kennedy (7) again reported that the persistence of morning glory is related to the large storage of starch in its roots and they found that arsenic could be used with some success in the control of morning glory but complete eradication was seldom accomplished by its use.

The work of Sturkie (19) on Johnson grass shows that any cutting reduces the root stock development and that the more frequently the cutting is made, the greater is the reduction. He showed that cutting late in the season reduced the food reserve much more than the weight of the rootstocks indicated. The largest yield of tops was obtained when the plants were cut at the time the seed was in the late milk stage. Cutting prior to this time reduced the top growth the second year. Fifty per cent more top growth was produced by those plants which had a well-developed system of rootstocks than plants without such a system because they had been cut in immature stages.

Aldous (2) found that the organic reserves in perennial herbaceous plants decreased from spring up to the time of flowering and then increased again until the close of the season. Greatest effectiveness of cutting was observed to be when the reserves were lowest.

Neller (14) concluded that the treatment of bindweed with chlorates must be sufficient to lower the catalase activity of the roots to a depth of 2 feet in order to obtain eradication.

In a study of the reserves in the roots of five perennial weeds, Arny (3) found in general that the readily available carbohydrate reserves were relatively lower in the early part of the season near the time of blooming, but rapidly accumulated from that time until the end of the season.

MATERIALS AND METHODS

The materials used for this investigation were roots from bindweed (*Convolvulus arvensis*) growing on experimental plats located 4 miles south of Fort Collins, Colorado. All samples for analyses of food reserves were taken on August 5, 1935. The plats from which samples were taken were all characterized by heavy growth of bindweed at the beginning of the test on June 10, 1935, when all the plats with the exception of the control were plowed and harrowed. These plats were cultivated on June 18 and again on June 25 in order to get the soil in uniform shape. The "weekly plats" received seven cultivations from the beginning of the test on June 10 until the time when samples were taken, on August 5. The "bi-weekly plats" received four cultivations from the beginning of the test until the date when samples were taken. The plats cultivated at 3-week intervals received three cultivations from the beginning of the test until samples were taken. The control plat was undisturbed throughout this period.

Samples of the root tissue were removed from the upper 12 inches and also from the 12- to 24-inch layer of soil in all cases. Each sample is a composite from four to five locations representing not less than 4 cubic feet of soil in each plat.

Immediately after digging, the samples from each plat were enclosed in an air-tight container and taken to the laboratory, washed free of adhering soil and sand, the excess water removed by blotting with cheesecloth, and duplicate 50-gram samples accurately weighed on a torsion balance. This was cut over and allowed to fall into pint mason fruit jars containing 175 cc of boiling 95% alcohol, sealed, and allowed to simmer on the boiling water bath 45 to 60 minutes.

After storage for 2 weeks, a series of extractions with 80% alcohol was made, the extract cooled after each extraction and filtered into 1-liter volumetric flasks. Two hundred cc portions of this liquor were used for the sugar determinations. The alcohol was removed by evaporation, the resulting water solution cleared with neutral lead acetate, and reducing substances determined by the Munson-Walker (13) method for the precipitation of the cuprous oxide and a modification of the Bertrand (6) method for the estimation of copper. Sucrose was calculated in terms of dextrose as the difference between total sugar, after invertase hydrolysis, and the reducing sugars.

The residue, after the removal of soluble carbohydrates, was dried to constant weight at 100° C, ground in a ball mill to 200-mesh fineness, and analyses made on 1-gram samples for polysaccharides (4).

The dextrin fraction was determined according to the method suggested by Loomis (12), removed by extraction with 10% alcohol, cleared with neutral lead acetate made to 250-cc volume, filtered, and 200-cc portions hydrolyzed with N/20 HCl at 120° C for 1 hour (5), neutralized, and again made to 250 cc volume and determinations made for reducing substances on 50-cc portions.

The substances extracted with taka-diastase, designated as starch, were cleared and the same procedure was followed in estimating this fraction as described for the 10% alcohol solution fraction above.

After removal of the dextrin and starch the residue was hydrolyzed with 1 + 20 HCl at 120° C for 1 hour for the determination of acid hydrolyzable materials.

Estimations were made for both sugar and polysaccharides as milligrams of dextrose per gram of dry weight and expressed in percentage in the tables and graphs. These values are the averages of closely agreeing duplicate samples.

EXPERIMENTAL RESULTS

EFFECT OF CULTIVATION UPON VEGETATIVE GROWTH OF BINDWEED

Table 1 shows a series of field observations made upon the plants undergoing cultivation at 1-, 2-, and 3-week intervals from the beginning of the test until October 10, 1935. The condition and type of growth appears to be closely correlated with the various carbohydrate fractions set forth in a subsequent part of this paper.

TABLE 1.—*Condition of bindweed plants during cultivation, 1935.*

Date cultivated	Type of growth*
Plats 1 to 10 Inclusive	
June 10 (plowed and harrowed)	Heavy
June 18	Medium
June 25	Light
Plats 1, 6, 8, and 10 Cultivated Every Week	
July 2	Light
July 9	Medium
July 16	Light
July 23	Light
July 30	Light
Aug. 6	Very light
Aug. 13	Light
Aug. 20	Just emerging
Aug. 27	Very light, limited growth perhaps due to low temperature
Heavy rains Sept. 7, 8, and 9 delayed cultivation	
Sept. 14	Light
Sept. 21	Light
Sept. 28	Very light
Oct. 3	Very light
Oct. 10	None
Plats 2, 4, and 9 Cultivated Every 2 Weeks	
July 9	Heavy
July 30	Medium
Aug. 13	Medium
Aug. 27	Medium
Sept. 14	Medium
Sept. 28	Light
Plats 3, 5, and 7 Cultivated at 3-week Intervals	
July 16	Heavy, almost as dense as undisturbed
Aug. 6	Medium, about 50% coverage
Aug. 27	Heavy rosettes
Sept. 21	Numerous small plants

*Very light = 0 to ½ inch; light = ½ inch to 2½ inches; medium = 4 inches to 6 inches; and heavy = over 6 inches.

It will be noted that very little growth was produced in those plats undergoing cultivation at weekly intervals. Those plats cultivated biweekly produced medium growth and the plats cultivated every 3 weeks showed still more growth between cultivation dates. The density of the growth, however, decreased with advance of season under prolonged cultivation.

EFFECT OF CULTIVATION ON SUGAR CONTENT OF BINDWEED ROOTS

Interesting and significant responses are observed in the sugar content of bindweed roots under different cultural practices.

Reducing sugars.—Hexose sugars are commonly assumed to be readily available and the source of respirable material in plants. The observed reduction in sugar content even under the light cultivation of once in 3 weeks may be interpreted as meaning that these sugars are being rapidly used in respiration to produce new shoots.

A study of Table 2 and Figs. 1 and 2 shows that the hexose sugars are relatively more rapidly depleted than is sucrose under cultivation at 3-week intervals as compared with uncultivated plats. Our data show that this response is obtained in both the first and second

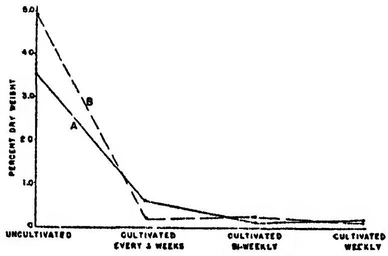

Fig. 1.—Reducing sugar content of bindweed roots, undisturbed and under cultivation at 1-, 2-, and 3-week intervals. Samples taken August 5, 1935. A, surface foot level; B, second foot level.

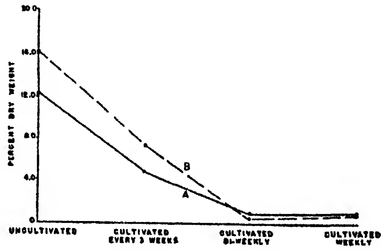

Fig. 2.—Sucrose content of bindweed roots, undisturbed and under cultivation at 1- 2-, and 3-week intervals. Samples taken August 5, 1935. A, surface foot level; B, second foot level.

foot levels, although there is a somewhat more rapid decline in the hexose sugars in the 12- to 24-inch depth than in the first foot level. The quantity of this sugar is reduced about 83% in the latter region, while there is a reduction of about 96% in the roots from the 12- to 24-inch depth. It is suggested that a possible explanation for this response may be the partial replacement of these sugars in the more shallow roots by the young shoots which have developed a relatively large assimilating area in the 3-week period. There seeems to be no significant difference in the hexose sugar content in the roots whether cultivated at 1-, 2-, or 3-week intervals.

Sucrose.—The data presented in Table 2 show that the sucrose is more slowly removed from the roots of bindweed under cultivation at 3-week intervals as compared with uncultivated plats than are the hexose sugars. A decline of 80 to 95% of the hexose sugars is obtained by this treatment, while but 55 to 60% of the sucrose is removed. It will be noted that the roots from the plats cultivated at 3-week intervals contained 38 to 44% of the amount of sucrose which was found in the undisturbed plants. Those plats, however, which underwent cultivation at intervals of 2 weeks showed a marked depletion in sucrose content. Increasing the frequency of cultivation to bi-weekly intervals caused about 92 and 99% removal of sucrose from the roots in the first and second foot levels, respectively. It is

TABLE 2.—*Percentage of various carbohydrate fractions in the roots of bindweed, August 5, 1935.**

Fraction	Uncultivated		Cultivated every 3 weeks		Cultivated every 2 weeks		Cultivated weekly	
	0–12 in.	12–24 in.	0–12 in.	12–24 in.	0–12 in.	12–24 in.	0–12 in.	12–24 in.
Reducing sugars	3.68	4.85	0.64	0.16	0.05	0.21	0.11	0.05
Sucrose	12.36	16.58	4.76	7.20	0.94	0.09	0.58	0.49
Total sugars	16.04	21.43	5.40	7.36	0.99	0.30	0.69	0.54
Dextrin	3.43	3.43	2.62	3.25	2.37	2.75	2.16	1.81
Starch	14.88	14.25	2.37	3.12	1.69	2.21	1.87	1.87
Acid hydrolyzable	19.40	18.25	20.50	21.10	22.40	22.15	22.60	24.10
Total polysaccharides	37.71	35.93	25.49	27.47	26.46	27.11	26.63	27.78
Total carbohydrates	53.75	57.36	30.89	34.83	27.45	27.41	27.32	28.32
Average First and Second Foot Levels								
Total sugars	18.73		6.38		0.64		0.61	
Dextrin	3.43		2.93		2.56		1.98	
Starch	14.56		2.74		1.94		1.87	
Acid hydrolyzable	18.82		20.80		22.27		22.35	
Total polysaccharides	36.82		26.48		26.78		26.20	
Total carbohydrates	55.55		32.86		27.43		27.83	
Readily available carbohydrates (sugars, dextrin, and starch)	36.72		12.05		5.15		5.46	

*Condensed table showing the percentage values which are averages of closely agreeing duplicate samples in each case.

observed, therefore, that for sucrose at least, there seems to be a distinct advantage in performing the cultivation operations at 2-week intervals rather than allowing the weed to grow 3 weeks undisturbed (Fig. 2). It is also of economic importance to note that no significant additional decline in this carbohydrate fraction was obtained by cultivating at intervals shorter than 2 weeks.

Total sugars.—Table 2 and Fig. 3 present the results of the total sugar content of the roots from bindweed under the different cultural practices. A comparison of the values in Table 2 shows that the trend of total sugars was governed chiefly by the sucrose content, this is also shown graphically in Figs. 1, 2, and 3. The percentage removal of total sugars from each of the two depths closely par-

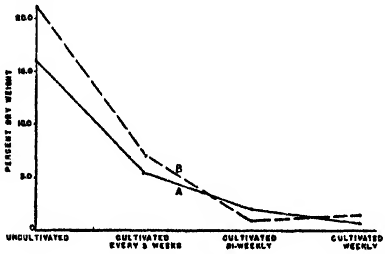

FIG. 3.—Total sugar content of bindweed roots, undisturbed and under cultivation at 1-, 2-, and 3-week intervals. Samples taken August 5, 1935. A, surface foot level; B, second foot level.

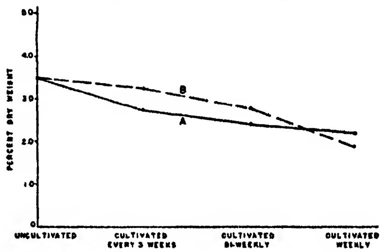

FIG. 4.—Dextrin content of bindweed roots, undisturbed and under cultivation at 1-, 2-, and 3-week intervals. Samples taken August 5, 1935. A, surface foot level; B, second foot level.

allels the other and about 65% depletion was observed in both cases under the longer intervals between cultivations. Increasing the frequency of cultivation from once in 3 weeks to bi-weekly periods reduced the average total sugar content in the two depth levels an additional 30%. In other words, at the date of sampling after bi-weekly cultivation from June 10 to August 5, 1935, the roots of the plants contained only about 4% of the total sugars found in the roots from the plants in the undisturbed plats. As we would expect, no significant differences were obtained in the total sugar content from the roots of plants cultivated bi-weekly or at weekly intervals.

EFFECTS OF CULTIVATION UPON POLYSACCHARIDE CONTENT OF BINDWEED ROOTS

Dextrin.—Reference to Table 2 and a study of Fig. 4 reveal that the percentage of dextrin in the roots did not fluctuate greatly under different cultural practices, although there seems to be a slight decline in the values of this carbohydrate by systematic cultivation of the weed. Since dextrin is ordinarily considered to be a transition product between starch and the sugars, a marked decrease in this fraction would not be expected until the starch was exhausted. Statistical analysis of the data showed that the differneces obtained between the two depth levels were not significant for this carbohydrate fraction.

Although it was found that the values for dextrin in the roots of plants undergoing cultivation at 7-day periods was about 58% of that in the undisturbed plants, the variation in the two depths was so great that statistically the decline did not appear to be significant. It is believed that further investigation with a study of a larger number of samples will indicate that cultivation may bring about greater depletion of this fraction than these data seem to show.

Starch.—The carbohydrate fraction extracted with taka-diastase and designated in this paper as starch is shown to be the polysaccharide most affected by the cultivation methods used. The trend of the materials extracted with take-diastase followed more closely the curve representing the reducing sugar content than any other carbohydrate fractions studied. The roots from the plants cultivated at intervals of 3 weeks contained about 19% of the amount of starch found in the undisturbed plants. Comparison of Figs. 4 and 5 shows that, while the starch fraction was markedly depleted, the dextrin values changed but very little under the differential cultivation treatments. The behavior of these fractions is in line with our concept of the relation between starch, dextrin, and the sugars. If dextrin is a transition product between starch and the sugars, then it would seem reasonable to believe that the starch would be more affected by cultivation than would the dextrin.

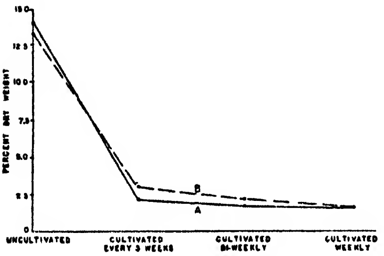

FIG. 5.—Starch content of bindweed roots, undisturbed and under cultivation at 1-, 2-, and 3-week intervals. Samples taken August 5, 1935. A, surface foot level; B, second foot level.

Occasional cultivation produced significant differences in the starch content from the roots of plants, although analyses of the roots from plants under bi-weekly and weekly cultivation practices showed no significant additional depletion of starch.

From Fig. 5 we observe that after cultivation about 2.5% starch, on the dry weight basis, still remained in the roots. This value obtains even in the last stages of starvation when the weed was cultivated every 7 days. We interpret this response to mean that starch may be the chief form of carbohydrate reserve material in the roots of bindweed. We believe it is significant that this residual supply of starch remained in the roots after the soluble carbohydrates had been almost entirely depleted. Our data show that less than 1% of the tissue, on the dry weight basis, was soluble carbohydrates after the weekly cultivation periods.

Although both the soluble carbohydrates and the starch fractions are depleted at comparable rates, it is observed that after the readily available soluble carbohydrates were exhausted, considerable reserve food remained in the form of dextrin and starch. It is believed that the difficulties encountered in attempts to control bindweed by cultural practices and application of chemicals is closely correlated with the food reserves in the form of starch in the roots.

These data seem also to point to the possibility that further investigation may reveal methods of analysis specific for starch, together with the sugars and possibly dextrin, and that these fractions alone may be used to indicate the trend of the food reserves in bindweed.

Assuming that treatments which will exhaust these fractions in the root will give us fairly exact control methods, we question the advisability of making complete analyses of all carbohydrate fractions in the root tissue for preliminary studies on reserve foods. Complete analyses must, however, be carried out for a more thorough understanding of the physiology of this plant.

Acid hydrolyzable substances.—There is a slight but apparent increase in the acid hydrolyzable substances with increased frequency of cultivation. This is in accordance with our concept of the cell wall structure and total residual dry matter of the protoplast. The slow but constant removal of the less readily available carbohydrate material from the cell, brought about by cultivation, results in an increase in the percentage of hemicelluloses and cellulose which constitute the cell wall structure laid down in early development and which make up the dry weight of the root material.

Total polysaccharides.—The decline observed in the total polysaccharide content brought about by cultivation at 3-week intervals seems to be due chiefly to the decrease in the starch fraction. Moreover, the relatively high values for the total polysaccharides in the roots of plants cultivated bi-weekly and weekly are shown (Table 2, Fig. 6) to be the result of considerable quantities of acid hydrolyzable

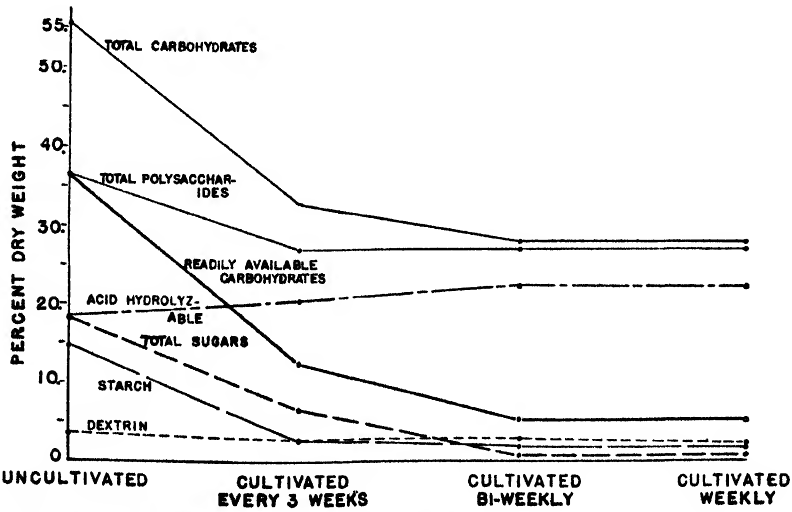

FIG. 6.—Average of the first and second foot levels of (a) total sugars, (b) dextrin, (c) starch, (d) acid hydrolyzable substances, (e) total carbohydrates, (f) total polysaccharides, and (g) readily available carbohydrates in the roots of bindweed, undisturbed and under cultivation at 1-, 2-, and 3-week intervals. Samples taken August 5, 1935.

substances. From a study of Table 2 and Figs. 2, 3, and 6 it appears that starch bears somewhat the same relation to the polysaccharide content as sucrose does to the total sugars.

No variation was found when determinations were made for dry matter content with frequency of cultivation, although the roots of the plants under cultivation were somewhat larger than those of the undisturbed plants.

Carbohydrate relationships.—A comparison of the rate of decline of the different carbohydrate fractions and their behavior under differential cultivation treatments may throw some light upon their relation to regeneration.

The values for all the carbohydrate fractions studied seemed to run very much the same for both the first and second foot. Therefore, the values for some of the fractions were averaged for the two depths and a comparison made of the rate of decline of each, together with the decline of total carbohydrates, total polysaccharides, and readily available carbohydrates. These data are presented in Table 2 and are shown graphically in Fig. 6. The term "readily available carbohydrates" as used here refers to the sugars, starch, and dextrin which are thought to be closely related to regeneration.

The total sugars and the starch show about the same rate of decrease with cultivation at 3-week intervals. The total sugars were about 4% higher than the starch on the dry weight basis in the roots of both undisturbed and cultivated plants. More frequent cultivation showed considerable effect upon the sugar values while the starch remained unchanged. This condition might be explained on the basis that the sugars are more readily available and are utilized for regeneration before the starch but are constantly replaced by photosynthesis during the 3-week growing period. The reduced photosynthetic area in the plants cultivated bi-weekly would be expected to result in a decrease in the rate at which the sugar is replenished, and regeneration of new shoot growth would lower the sugar content.

It is difficult to attach any important value to the trend of the acid hydrolyzable fraction since it is not ordinarily believed to be available as a reserve carbohydrate. Furthermore it is not likely that dextrin, as such, functions as a reserve carbohydrate if we assume it to be a transition product between starch and the sugars. The uniformity of the dextrin and acid hydrolyzable fractions tends to decrease the apparent rate of the total polysaccharide depletion.

The trend of the total carbohydrates and the readily available carbohydrates closely parallel one another, differing only in the acid hydrolyzable substances. It seems, therefore, that the readily hydrolyzable carbohydrates, namely the sugars, dextrin, and starch should warrant considerable study to determine their relation to regeneration and control of bindweed.

CONCLUSIONS AND SUMMARY

Data have been presented to show that the percentage of reducing sugars in bindweed roots cultivated at 3-week intervals was markedly lower than that found in the roots of undisturbed plants. A slight

additional decrease was observed in the roots from the first foot level of plants cultivated bi-weekly.

The roots of plants cultivated at 3-week intervals contained 55 to 60% less sucrose than the roots of undisturbed plants, while those cultivated bi-weekly showed 92 and 99% depletion of sucrose in the first and second foot levels, respectively.

The total sugar content followed very closely the trend of the sucrose and was governed chiefly by this fraction.

The polysaccharide fraction extracted with 10% alcohol and designated "dextrin" showed slow but constant depletion as a result of cultivation. The roots of plants cultivated every 7 days throughout the experiment contained 58% of the quantity of dextrin found in the check plants.

The data further show that the starch content of the roots of bindweed was decreased markedly when the plants were cultivated at 3-week intervals, while more frequent cultivation caused but very little additional depletion of this fraction.

An important observation to be made as a result of this study is the marked depletion of the total carbohydrates in the roots of plants which had undergone systematic cultivation. Prolonged cultivation, either occasional or frequent, caused a significant decrease in the food materials stored in the roots. This was found to be true of the plants in this investigation which were under cultivation at intervals of 3 weeks or less. Slight additional decrease was observed with increased frequency of cultivation.

It is suggested that total carbohydrate analyses may be used, or that improved methods based on the detection of specific carbohydrate fractions may be developed, which should simplify investigations where large numbers of samples are to be studied.

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A COMPARISON BETWEEN MEXICAN JUNE AND THREE OTHER VARIETIES OF CORN FOR SUMMER PLANTING[1]

C. K. McCLELLAND[2]

MEXICAN June has long been one of the popular corn varieties in the South for late planting, but there have been few controlled experiments made in support of the claim. At the Arkansas Experiment Station this variety has been used in a date-of-planting test along with other varieties and a number of comparisons between it and the others are available for study. The plantings began April 1 in most cases, but this report covers only those made June 1, June 15, and July 1. The experiments were conducted at Fayetteville in northwest Arkansas, at Scott in central Arkansas, and at Marianna in eastern Arkansas and date back as far as 1920 when experiments were begun on the present University Farm. Neal's Paymaster, Funk's 90 Day, and Hasting's Prolific corn are the varieties included with Mexican June in the experiments.

Table 1 gives the yields of these varieties for the years 1920 to 1935 at Fayetteville, 1922 to 1928 at Scott, and 1927 to 1935 at the Cotton Branch Station at Marianna. The respective averages are given, the differences between the Mexican June and the other varieties, and the odds against the chance occurrence of such differences as calculated by Student's method of comparison which seems to be the method best suited to the consideration of these differences.

At Fayetteville, the Mexican June in June 1 plantings showed significant gain only over the Hasting's Prolific variety. At Scott, it fell below Paymaster and showed only slight gains over the other two varieties. At Marianna, it proved to be superior to the other varieties by 6.74 to 15.65 bushel averages though the gain over Paymaster was not consistent enough to establish significance. If all of the tests of this date be combined into one group, the Mexican June is found to be superior to the Hasting's Prolific by high odds, better than Funk's 90 Day by good odds, while it did not show consistent gains over the Paymaster and the odds were lower than what is required to establish significance.

Table 2 gives the yields of the several varieties when planted June 15. At Fayetteville, the June corn surpasses the other three but on account of the variability the difference between it and Funk's 90 Day is not significant. At Scott, greater superiority of the Mexican June over Funk's 90 Day than over Paymaster or Hasting's Prolific is shown, but again the differences failed to reach significance. At Marianna, slight difference as compared to Paymaster but marked differences over the other varieties are shown. When the results at all three places are combined, the superiority of Mexican June for the June 15 planting is well established.

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[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Published by consent of the Director as Research Paper No. 443 Journal Series of the University of Arkansas. Received for publication July 18, 1936.

[2]Assistant Agronomist.

TABLE 1.—*Comparisons of yields of June 1 plantings of Mexican June, Paymaster, Hasting's Prolific, and Funk's 90-Day corn.*

Year of planting	Yields in bushels per acre				Increase of Mexican June over		
	Mexican June	Pay-master	Hasting's Prolific	Funk's 90 Day	Pay-master	Hasting's Prolific	Funk's 90 Day
	Fayetteville						
1920	35.5	30.4	—	26.5	5.1	—	9.0
1921	51.9	36.7	—	—	15.2	—	—
1922	23.4	35.8	—	24.0	—12.4	—	— 0.6
1923	2.3	8.3	—	12.6	— 6.0	—	—10.3
1924	56.4	56.7	36.9	55.2	— 0.3	19.5	1.2
1925	14.6	8.9	10.6	23.0	5.7	4.0	— 8.4
1926	44.7	33.3	40.1	25.4	11.4	4.6	19.3
1927	59.1	25.8	29.8	49.2	33.3	29.3	9.9
1928	36.4	31.9	31.1	32.7	4.5	5.3	3.7
1929	18.9	14.8	21.1	9.1	4.1	— 2.2	9.8
1930	33.1	13.4	14.4	37.3	19.7	18.7	— 4.2
1931	38.1	39.1	24.1	45.1	— 1.0	14.0	— 7.0
1933	43.0	54.3	33.8	45.1	—11.3	9.2	— 2.1
1935	27.4	31.6	—	—	— 4.2	—	—
Total	484.8	421.0	241.9	385.2	63.8	102.4	20.3
Average	34.62*	30.07	26.87	32.1	4.55	11.38	1.69
Odds against chance occurrence					10.6:1	212:1	2.84:1
	Scott						
1922	48.5	60.5	41.9	43.5	—12.0	6.6	5.0
1923	16.0	28.5	26.3	31.3	—12.5	—10.3	—15.3
1924	28.6	39.7	32.3	15.3	—11.1	— 3.7	13.3
1925	57.4	26.0	30.2	34.0	31.4	27.2	23.4
1926	53.0	41.4	45.5	42.9	11.6	7.5	10.1
1927	23.6	26.0	30.5	31.6	— 2.4	— 6.9	— 8.0
1928	23.3	35.3	30.3	28.1	—12.0	— 7.0	— 4.8
Total	250.4	257.4	237	226.7	— 7.0	13.4	23.7
Average	35.8	36.8	33.85	32.38	— 1.0	1.95	3.39
Odds against chance occurrence					11.2:1	2.12:1	3.08:1

Marianna

1927	69.3	67.4	57.8	33.7	1.9	11.5	35.6
1928	52.4	45.7	44.7	39.2	6.7	7.7	13.2
1929	50.7	25.3	23.1	28.6	25.4	27.6	22.1
1930	5.7	0.4	2.3	1.8	5.3	3.4	3.9
1931	58.0	45.6	44.7	37.3	12.4	13.3	20.7
1932	22.6	23.7	17.1	10.5	— 1.1	5.5	12.1
1933	29.5	35.2	—	27.6	— 5.7	—	1.9
1934	—	—	—	—	9.0	—	—
1935	20.4	11.4	—	—	—	—	—
Total	308.6	254.7	189.7	178.7	53.9	69.0	109.5
Average	38.57†	31.83	31.61	25.52	6.74	11.5	15.65
Odds against chance occurrence					17.8:1	142:1	163:1
Total 3 locations	1,043.8	933.1	668.6	790.6	110.7	184.8	153.5
Average‡	35.99	32.17	30.39	30.40	3.82	8.4	5.91
Odds against chance occurrence					15.2:1	713:1	102:1

*1924–1933 average is 38.25 bushels; for 1920–33 without 1921, average is 33.79 bushels.

†1927–1932 average is 43.11 bushels; for 1927–1933 the average is 41.17 bushels.

‡The averages of all locations for Mexican June in comparison with Paymaster is 35.99 bushels; with Hasting's Prolific, 38.79 bushels; and with Funk's 90 Day, 36.31 bushels.

TABLE 2.—*Comparisons of yields of June 15 plantings of Mexican June, Paymaster, Hasting's Prolific, and Funk's 90 Day corn.*

Year of planting	Yields in bushels per acre				Increase of Mexican June over		
	Mexican June	Paymaster	Hasting's Prolific	Funk's 90 Day	Paymaster	Hasting's Prolific	Funk's 90 Day
	Fayetteville						
1920	31.7	38.1	—	20.2	−6.4	—	11.5
1921	53.0	41.1	—	—	11.9	—	—
1922	29.3	23.0	—	10.4	6.3	—	18.9
1923	10.5	14.5	—	8.0	−4.0	—	2.5
1924	49.4	43.9	24.3	52.3	5.5	25.1	−2.9
1925	12.0	6.7	3.9	16.6	5.3	8.1	−4.6
1926	37.0	52.6	42.4	39.9	−15.6	−5.4	−2.9
1927	44.9	21.6	18.3	35.1	23.3	26.6	9.8
1928	38.7	29.1	18.1	25.6	9.6	20.6	13.1
1929	27.8	14.0	23.5	8.3	13.8	4.3	19.5
1930	35.0	13.0	17.3	65.6	22.0	17.7	−30.6
1931	30.2	28.0	12.7	36.9	2.2	17.5	−6.7
1933	48.5	31.4	36.1	30.0	17.1	12.4	18.5
1935	19.0	17.9	—	—	1.1	—	—
Total	467.0	374.9	196.6	348.9	92.1	126.9	46.1
Average	33.35	26.77	21.84	29.07	6.58	14.07	3.84
Odds against chance occurrence					39.3:1	475:1	3.64:1

Scott							
1922	55.2	50.6	36.5	28.6	4.6	18.7	26.6
1923	31.1	25.9	15.5	19.7	5.2	15.6	11.4
1924	43.5	52.2	31.1	14.7	— 8.7	12.4	28.8
1925	58.5	29.8	30.2	27.8	28.7	28.3	30.7
1926	31.2	37.7	58.1	36.3	— 6.5	—26.9	— 5.1
1927	22.7	41.6	30.3	28.7	—18.9	— 7.6	— 6.0
1928	34.6	43.7	59.7	33.1	— 9.1	—25.1	1.5
Total	276.8	281.5	261.4	188.9	— 4.7	15.4	87.9
Average	39.54	40.2	37.34	26.98	— .68	2.2	12.55
Odds against chance occurrence					6.50:1	1.46:1	19.5:1
Marianna							
1927	44.9	56.2	47.5	41.1	—11.3	— 2.6	3.8
1928	52.1	46.0	27.0	28.0	6.1	25.1	24.1
1929	45.0	32.4	21.4	27.3	12.6	23.6	17.7
1930	12.0	2.3	7.5	5.7	9.7	4.5	6.3
1931	47.9	36.9	7.8	2.7	11.0	40.1	45.2
1932	27.7	13.7	21.4	11.4	14.0	6.3	16.3
1933	23.2	24.7	—	41.2	— 1.5	—	—18.0
Total	252.8	212.2	132.6	157.4	40.6	97.0	95.4
Average	36.11	30.31	22.10	22.48	5.8	16.16	13.63
Odds against chance occurrence					11.2:1	54.9:1	45.7:1
Total 3 locations	996.6	868.6	590.6	695.2	128.0	239.3	229.4
Average	35.59	31.02	26.84	26.74	4.57	10.88	8.82
Odds against chance occurrence					41.2:1	243:1	155:1

TABLE 3.—*Comparisons of yields of July 1 plantings of Mexican June, Paymaster, Hasting's Prolific, and Funk's 90 Day corn.*

Year of planting	Yields in bushels per acre				Increase of Mexican June over		
	Mexican June	Paymaster	Hasting's Prolific	Funk's 90 Day	Paymaster	Hasting's Prolific	Funk's 90 Day
	Fayetteville						
1920	28.0	33.3	—	21.1	—5.3	—	6.9
1921	33.0	28.9	—	—	4.1	—	—
1922	37.7	20.5	—	12.9	17.2	—	24.8
1923	11.0	15.5	—	11.7	—4.5	—	—0.7
1924	45.3	35.1	22.6	37.9	10.2	22.7	7.4
1925	9.7	6.5	5.7	5.2	3.2	4.0	4.5
1926	26.4	43.8	31.3	27.4	—17.4	—4.9	—1.0
1927	29.2	16.7	9.1	27.0	12.5	20.1	2.2
1928	29.2	28.0	27.8	20.4	1.2	1.4	8.8
1929	32.8	17.9	19.0	14.7	14.9	13.8	18.1
1930	31.4	13.4	18.2	8.2	18.0	13.2	23.2
1931	21.3	10.6	3.4	9.0	10.7	17.9	12.0
1933	28.7	20.9	20.2	6.5	7.8	8.5	22.2
1935	21.9	4.6	—	—	17.3	—	—
Total	385.6	295.7	157.3	202	89.9	96.7	128.4
Average	27.54	21.12	17.47	16.83	6.4	10.74	10.76
Odds against chance occurrence					52.2:1	138:1	163:1
	Scott						
1922	48.3	28.2	15.4	25.8	20.1	32.9	22.5
1923	20.9	22.6	24.5	17.1	—1.7	—3.6	3.8
1924	46.5	41.3	35.3	14.8	5.2	11.2	31.7
1925	32.0	27.2	26.7	20.0	4.8	5.3	12.0
1926	55.3	53.0	63.2	43.1	2.3	—7.9	12.2
1927	18.9	19.7	22.4	29.0	—0.8	—3.5	—10.1
1928	47.3	45.5	34.1	40.4	1.8	13.2	6.9
Total	269.2	237.5	221.6	190.2	31.7	47.6	79
Average	38.5	33.9	31.65	27.17	4.6	6.85	11.28
Odds against chance occurrence					16:1	6.50:1	16:1

	Marianna						
1927	47.2	42.4	36.6	16.7	4.8	10.6	30.5
1928	54.0	55.6	39.8	33.1	— 1.6	14.2	20.9
1929	16.0	33.2	23.0	26.0	—17.2	— 7.0	—10.0
1930	17.3	13.4	1.9	1.9	3.9	15.4	15.4
1931	49.5	45.8	25.6	19.9	3.7	23.9	29.6
1932	22.7	19.7	21.6	7.2	3.0	1.1	15.5
1933	—	—	—	—	—	—	—
1934	9.0	28.8	—	—	—19.8	—	—
1935	12.3	30.6	—	—	—18.3	—	—
Total	228.0	269.5	148.5	104.8	—41.5	58.2	101.9
Average	28.5	33.68	24.75	17.46	— 5.2	9.7	17.0
Odds against chance occurrence					4.14:1	27.7:1	50.8:1
Total 3 locations	882.8	802.7	527.4	497.0	80.1	202.5	309.3
Average	30.44	27.67	23.97	19.88	2.76	9.2	12.37
Odds against chance occurrence					8.5:1	1999:1	9999:1

Table 3 gives the results from the July 1 plantings. At Fayetteville, the superiority of the Mexican June over the other varieties is clearly shown in spite of some negative results in 1920, 1923, and 1926. At Scott, the differences are positive but not conclusive. At Marianna, the Paymaster variety showed slight superiority, but the Mexican June was markedly better than Funk's 90 Day or Hasting's Prolific.

SUMMARY

When the results at the three locations are combined, Mexican June proved by high odds to be better than Funk's 90 Day or Hasting's Prolific but only slightly superior to Paymaster.

Since, if variability remains constant, the odds increase so rapidly as numbers increase, there seems to be no need to combine the data from the three dates of planting further. It is quite clearly proved that Mexican June is entitled to the first place it has long held among farmers as a superior variety for summer planting. Paymaster is shown to be of secondary value but much closer to Mexican June for summer planting than Funk's 90 Day or Hasting's Prolific.

EFFECT OF DEFOLIATION UPON THE COLD RESISTANCE OF WINTER WHEAT[1]

C. A. SUNESON AND GEORGE L. PELTIER[2]

SINCE fall pasturing of winter wheat fields has become somewhat common as a practice in the Great Plains regions, preliminary experiments were undertaken to determine the effect of defoliation upon the subsequent cold resistance of winter wheat plants defoliated to varying extents in the early tillering stage of development.

There is apparently little experimental information at hand to assist in properly appraising the real or potential damage from such conditions. Dexter[3] does not regard defoliation as detrimental to the hardiness of dormant winter wheats, unless environmental conditions in late winter are such as to stimulate top growth with subsequent rapid depletion of organic food reserves. Our results, based on defoliation during the hardening period, are not in agreement with this statement.

MATERIAL AND METHODS

Two experiments were conducted during the winter of 1935–36. One was with Cheyenne wheat in which the plants were defoliated in various degrees on November 15 and frozen 5 and 21 days afterwards. In one lot the first leaf only was removed, in another the first two leaves were removed, and in a third all leaves were removed, the plants being cut off ½ inch above the ground surface. A non-defoliated lot was included as a control. At the time of freezing, on November 20, the fifth leaf was making its appearance on a few plants of the control lot. In a second experiment, Cheyenne and Blackhull were defoliated November 13 and again December 9, and a second lot was defoliated November 13, November 20, and December 9. In all cases two-thirds of all fully developed leaves and of all previously undisturbed leaves were removed. In a third lot all leaves were removed to within ½ inch of the ground surface on December 9. Various lots of these were frozen at intervals from November 25 to February 20, as indicated later. As before, non-defoliated lots were included as checks. The fully defoliated plants in this experiment made no perceptible growth after defoliation; in fact there was a tendency for them to die back to the ground level.

The plants emerged on October 21, 1935, and reached the early tillering stage late in November. Hence they were of a size and stage of development near the lower limits commonly pastured. Hardening, as evidenced by effective lethal temperatures, was about average, considering our 6 years of experience with con-

[1]A preliminary paper based on cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Departments of Agronomy and Plant Pathology, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director as Journal Series Paper No. 179 of the Nebraska Agricultural Experiment Station. Received for publication July 25, 1936.

[2]Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Plant Pathologist, Nebraska Agricultural Experiment Station, respectively. The writers wish to acknowledge the assistance of R. O. Weibel in conducting the experiments.

[3]DEXTER, S. T. Decreasing hardiness of winter wheats in relation to photosynthesis, defoliation, and winter injury. Plant Phys., 8:297–304. 1933.

trolled freezing experiments. The loss of hardening in January and February, however, was below average.

The freezing technic employed was essentially the same as that reported earlier[4] for field-grown plants. Each flat was divided to include all the treatments being compared, each with an equal exposure and random positional placement. This involved 25 or more plants of each variable, in each of eight flats frozen on each date. Exposures were for a constant period of 24 hours at the indicated temperatures, which killed practically all live tissue above the ground level. Survivors were noted after 2 weeks of recovery in a 70° F greenhouse.

RESULTS

The survival of Cheyenne wheat in the first experiment is given in Table 1. It will be noted that the failure of the plants to survive was, in general, in proportion to the amount of vegetative tissue removed. Deferred freezing, i. e., December 6 as compared with November 20, apparently permitted the partially defoliated plants to increase somewhat in relative hardiness. Even the fully defoliated plants hardened somewhat, as evidenced by a higher percentage of survival despite exposure to a lower temperature (6° F). Incidentally, daylight temperatures and radiation during the interval, especially during the first week in December, were above the average.

TABLE 1.—*Comparative survival of Cheyenne winter wheat plants, variously defoliated on November 15, when frozen artificially 5 and 21 days after defoliation.*

Defoliation treatment	Date and intensity of exposure			
	November 20 (2° F)		December 6 (—4° F)	
	No. of plants exposed	Plant survival %	No. of plants exposed	Plant survival %
None (control)	225	76	232	91
First leaf removed	232	44	213	79
First 2 leaves removed	235	19	221	52
All leaves removed	214	15	229	19

The results obtained with the two varieties Cheyenne and Blackhull in the second experiment are given in Table 2. The results of this experiment also indicate the importance of a full complement of leaf surface to insure maximum cold resistance, the survival as before being approximately in proportion to the undisturbed foliage. The results, therefore, show that cold resistance of winter wheat plants in the early tillering stage of development may be modified by decreasing the photosynthetic area during the hardening period. It would thus appear that photosynthesis plays an important rôle in the hardening process.

[4]SUNESON, C. A., and PELTIER, GEO. L. Cold resistance adjustments of field-hardened winter wheats as determined by artificial freezing. Jour. Amer. Soc. Agron., 26:50–58. 1934.

TABLE 2.—*Effect of different defoliation treatments on the cold resistance of Cheyenne and Blackhull winter wheat plants in the early tillering stage.*

Defoliation treatments	Percentage survival after freezing on indicated dates and at specified temperatures						
	Nov. 25 0° F	Dec. 20 —11° F	Jan. 3 —13° F	Jan. 23 —10° F	Jan. 30 —8° F	Feb. 20 —4° F	Av.
			Cheyenne				
None (control)..	54	93	39	40	76	71	62
Defoliated twice.	22	79	17	6	48	47	37
Defoliated thrice	23	75	14	13	42	36	34
All leaves removed.....	27*	66	1	0	17	17	21
			Blackhull				
None (control)..	3	57	9	24	61	71	38
Defoliated twice.	3	11	3	4	23	25	12
Defoliated thrice	2	6	0	0	8	5	4
All leaves removed . .	4*	9	0	0	1	4	3

*Leaves removed November 20.

The changing relationships between the two varieties Cheyenne and Blackhull are also of interest, since it is not uncommon to observe adjustments in the relative hardiness of winter wheat varieties at progressive periods during the winter.[5] Under the conditions of this experiment the survival of Blackhull was in accordance with the normal relationship with respect to Cheyenne during the hardening period; but when frozen in February and the latter part of January, during which time a loss in hardening was noted, Blackhull survived relatively better than would be expected.

SUMMARY

Defoliation of field-grown winter wheat plants in the early tillering stage reduced cold resistance. The decrease in survival was approximately in proportion to the degree of defoliation, indicating the importance of photosynthesis during the hardening process.

[5]See footnote 4.

METHODS USED IN THE DETERMINATION OF RELATIVE AMOUNTS OF EAR ROT IN DENT CORN[1]

PAUL E. HOPPE AND JAMES R. HOLBERT[2]

EAR rot diseases of dent corn are among the most serious factors affecting both yield and quality of the crop throughout a major portion of the corn belt. While it is needless to dwell on data gathered by the Federal Grain Supervision which show the extent of low quality corn annually arriving at terminal markets, suffice it to say that, in 1926, when ear rots were especially bad, over 50% of all June receipts of corn arriving at terminal markets graded lower than No. 3 because of the factor "total damage," mostly kernel rot, and that in the 9-year period, 1923–24 to 1931–32, approximately 33 per cent of the market receipts of the average corn crop had their grade determined as lower than grade No. 1 because of this factor.

The possibilities of obtaining marked improvement in quality through selection in inbred lines and the use of ear-rot resistant lines in hybrids has focused attention on the problem in recent years. Hybrids have been obtained among the high-yielding strains recently developed which are more resistant and others which are more susceptible to the ear-rot diseases than are the best of the open-pollinated varieties. It is the purpose of the present paper to describe certain aspects of the technic used in connection with the breeding for ear rot resistance as employed in the cooperative corn breeding program in Illinois.

CONSISTENCY OF REACTION UNDER NATURAL INFECTION

In breeding for resistance to disease it is essential that the plants be subjected to the disease under consideration so that differentials in host reaction are obtained. In some instances artificial inoculations have been found to be both desirable and necessary as a means of obtaining best differentials. In the case of corn ear rot a satisfactory inoculation technic has not been developed, and dependence has been placed upon natural infection for the annual occurrence of disease. Until more is known about the nature of resistance to ear rots and the complex relationships of factors which modify the expression of resistance are more fully understood, it appears doubtful if a simple method for determining relative resistance can be applied which will give results as useful as those obtained under conditions of natural infection.

The reliability of determinations of ear-rot reaction from natural infection has been repeatedly demonstrated under Illinois conditions.

[1]Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Wisconsin Agricultural Experiment Station, the Illinois Agricultural Experiment Station, and Funk Bros. Seed Co., Bloomington, Ill. Received for publication July 30, 1936.

[2]Associate Pathologist and Senior Agronomist, respectively, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The writers are indebted to Mr. Eugene H. Herrling of the Plant Pathology Department, University of Wisconsin, for drawing the figures.

High inter-annual and inter-place correlations in the ear-rot reactions of many hybrids and varieties have been maintained in years when ear rots were especially prevalent as well as in years when the average disease level was much lower. For example, in a series of 25 inbreds, top-crossed with the open-pollinated Krug variety, the top crosses being grown at Hudson, Illinois, in 1933 and again in 1934, when the means for the percentages of rotted kernels were 5.4 and 16.3, respectively, the inter-annual correlation for ear-rot reaction was + 0.69. The graphical representation of the data (Fig. 1) shows that, with a few exceptions, the relative positions of the various entries were maintained fairly well despite the large difference in

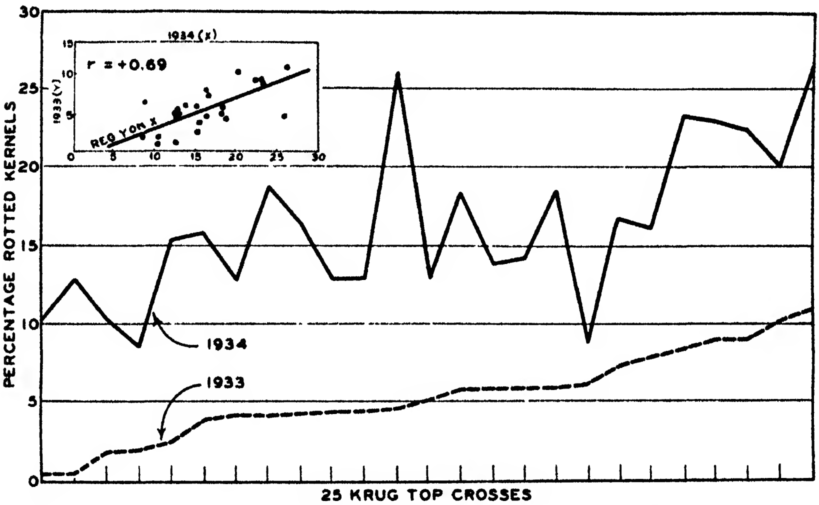

FIG. 1.—Percentages of rotted kernels (by weight) from natural infection in 25 Krug top crosses grown at Hudson, Ill., in 1933 and again in 1934. The level of infection was relatively low in 1933 but was much higher in 1934.

the disease levels in these two seasons. Another typical example is cited from data obtained in 1935 when a minimum of ear rot developed in Illinois. The inter-place correlation for ear-rot reaction in 44 hybrids grown at Stockton, Ill., and at Rochelle, Ill., was + 0.63 when the mean percentages of rotted kernels for the two locations were 7.2 and 2.4, respectively.

METHODS FOR MEASURING EAR ROT

The term "ear rot," or "kernel rot," is a broad term in that it includes a group of diseases caused by fungi which vary considerably in their parasitic capabilities. The problem of measuring the extent or relative amounts of ear rot in strains, on an ear separation basis, at once becomes complicated by the fact that symptoms and extent of damage in individual ears vary considerably, not only with different fungi but also with a given fungus and within relatively uniform inbred lines of corn. A complete gradient in extent of damage or rot

usually occurs, ranging from ears with just a few damaged kernels to ears that have been completely over-run and rotted by the fungus. Ears frequently are found which show slight external evidence of rot but which, upon being broken, will be found to be badly damaged. Difficulty always is encountered in attempts to classify entire ears as rotted or not rotted which lead to inaccuracies in measuring the amount of ear rot and in determining relative resistance.

A method which has given better results in measuring relative amounts of ear rot involves a separation of the rotted kernels from the sound kernels in a representative sample of grain of each strain. A sample of not less than 200 grams has been used for this purpose. It is obtained by making successive divisions, through a Boerner divider, of a larger sample representative of the strain. The rotted kernels are separated from the sound kernels and their percentage, by weight, is computed. This is essentially the method employed by the Federal Grain Division in determining "total damage" in carload lots of corn.

A direct comparison of the two methods of measuring the extent of ear rot, i. e., kernel separation vs. ear separation, was possible in experiments in which both methods were applied to the same field samples. The first experiment at Bloomington, Ill., in 1932, involved 37 hybrids and varieties. Ears were harvested from 50 hills or approximately 125 plants for each entry. The percentage of ears classed as rotted by count first was determined for each entry. The corn then was shelled and the percentage of rotted kernels determined as outlined above. The data obtained from the two methods for each of the 37 entries are graphically presented in Fig. 2.

If we accept the percentages of rotted kernels as representing the best estimates of the actual amounts of kernel rot in the samples, it is apparent that the results from the ear separation method are very inaccurate. The coefficient of correlation between the two methods is only + 0.40. The tendency for having been too severe among the resistant strains and too lenient among the susceptible ones when separations were made on the basis of the ear as a unit is quite evident.

The following season (1933) a modification of the ear separation method was compared with the kernel separation method. Thirty-six hybrids and varieties were used in this experiment. The percentage of rotted ears was determined by weight, the rotted separate including the completely rotted ears and the rotted portions only of the partly rotted ears. All bleached and otherwise doubtful looking ears were broken to see if the ears were rotted internally and, if so, were included in the rotted separate. A comparison of the results obtained by this method with those from subsequent kernel separations on the same samples is shown in Fig. 3. The tendency, observed in the previous experiment, for being too severe among the resistant strains and too lenient among the susceptible ones again is evident. The improvement in accuracy over the ear count method tested the previous year is apparent and is reflected in the higher coefficient of correlation, increased from + 0.40 to + 0.62. The two experiments described illustrate the difficulty of accurately measuring the amount of ear rot on the basis of units larger than the kernels.

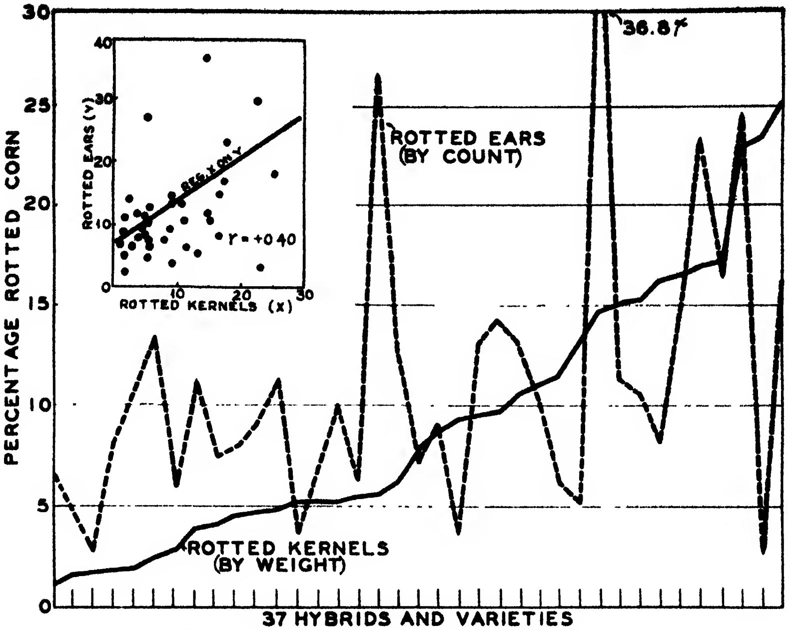

FIG. 2.—Comparison of the ear and kernel separation methods of measuring ear rot in corn. The percentage of ears classed as rotted first were determined in 37 hybrids and varieties. The samples then were shelled and the percentages of rotted kernels by weight were determined for each entry.

DELAYED HARVESTINGS BEST FOR EAR ROT STUDIES

Experiments conducted for several years in Illinois have shown that under conditions of natural infection the largest differentials in reaction of strains of corn to ear rot have been obtained when harvesting was delayed until the middle of November or later. Results obtained in 1932 serve to illustrate differences obtained in early and late harvestings. The harvestings were made on October 15 and again in the latter part of December. The averages for a number of hybrids, grouped into resistant, intermediate, and susceptible classes, are given in Table 1.

TABLE 1.—*Ear rot in hybrid strains of corn in harvestings made on October 15 and again during the latter part of December, 1932, at Bloomington, Ill.*

Strain group	Total number of ears examined in		Total percentage of rotted ears in		Percentage rotted kernels in December harvest
	October	December	October	December	
Resistant....	468	1,042	0.6	8.1	2.4
Intermediate.	614	1,454	1.7	10.9	8.0
Susceptible..	498	1,000	1.8	17.4	17.4

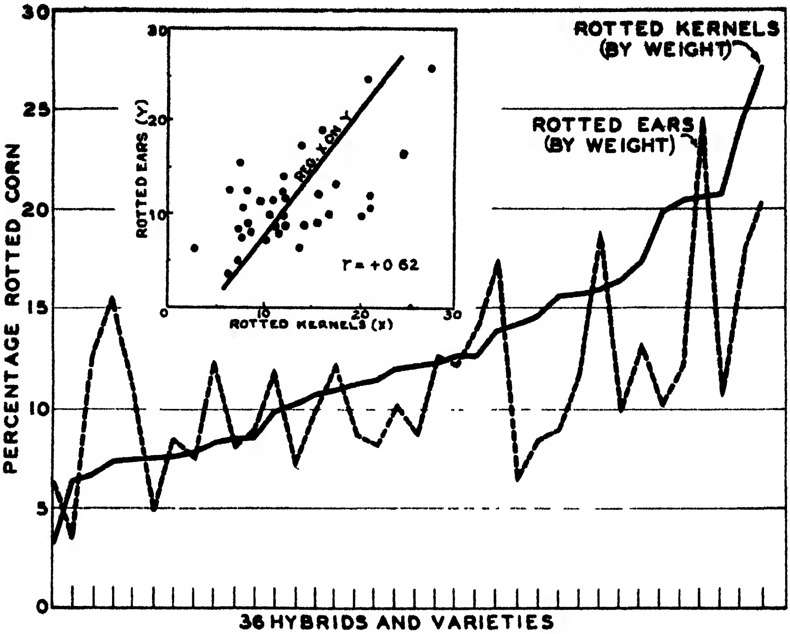

FIG. 3.—Comparison of two methods of determining ear rot in corn by weight. The percentages of rotted ears included ears totally rotted and the rotted portions of partially rotted ears.

In the October harvestings the percentage of ears rotted ranged from 0.6 in the resistant group to 1.6 in the susceptible group, whereas the December harvestings showed a range from 8.1% to 17.4% in the same groups. In the shelled samples from the December harvestings the percentage of rotted kernels was 2.4 in the resistant group and 17.4 in the susceptible group. Thus, the December harvestings showed not only more ear rot, but the differentials between resistant and susceptible strains were widened considerably. The inaccuracy of the ear separation method for measuring ear rot is again shown in the data from the December harvestings.

SAMPLING PROBLEMS

Sampling problems connected with the kernel separation method involve (1) field sampling which concerns the number of plants from which ears must be harvested in order that the shelled grain from them shall adequately represent the variety, and (2) sampling the shelled grain. Data presented in this paper are concerned entirely with the latter phase. Obviously, from the standpoint of expediency, it is desirable to use as small a sample as will give efficient results. An experiment was designed to study the amount of variability among samples of different sizes. Standard deviations computed for each sample size from 16 samples of that size were used as the measure of variability. Samples of 400, 200, 100, 50, and 25 grams were used.

The samples were obtained in the following manner: A 1,600-gram sample containing 5% rotted kernels, by weight, was obtained by mixing the proper amounts of sound and rotted kernels. This sample was thoroughly mixed and then divided six times by means of a Boerner divider. This resulted in 64 samples, theoretically of 25 grams each. The percentage of damaged kernels in each sample was then determined.

The data for the larger samples were obtained by combining those on a sufficient number of randomly selected 25-gram samples.

Arny and Dorchester,[3] in variability studies on heat damage and foreign material in wheat, used a similar method. They found no significant differences in variability whether the samples were taken in contiguous order or whether they were taken from different halves or from different quarters from the divider. In other words, randomized selections gave the same results as were obtained when the larger samples were made up from contiguous samples. In the present study it was arbitrarily decided to make 16 determinations for each sample size to be studied. An average was taken of the standard devitaions of four groups of 16 for the 25-gram samples and of two such groups for the 50-gram samples.

The determinations as described for the samples containing 5% kernel rot were repeated with samples containing 10, 15, 20, 25, 30, and 35% rot.

As previously stated, the standard deviation was used as the principal measure of the variability in the present studies. Standard deviations for each sample size in all of the disease levels studied are shown in Fig. 4. The curves show the tendency for the standard deviation to increase with the increase in kernel rot in the samples. This holds especially in the smaller samples. The tendency for the curves to flatten at the 200-gram sample size is also shown.

The statistical measurements used in the analysis of the data are shown in the column headings in Table 2. The data in this table are for the lot of corn with 5% diseased kernels. Similar analyses were made of the data from all the other disease levels included in the experiment. As the data in the table are illustrative and fairly representative of the results obtained at the higher disease levels, attention is briefly directed to some of the common tendencies shown. The close agreement between the actual standard deviations and the mathematical expectations for the various sample sizes would indicate that the sampling was well randomized. The table shows that with 25-gram samples a deviation of 4.64% from the mean may be expected on the basis of chance alone 5% or once in 20 times. Thus, in samples of this size, approximately from 0 to 10% kernel rot could be ascribed as chance variation from 5%. A significant difference (5% point) for the 200-gram samples drops to 1.58 and reduces the chance variability roughly to a range between 3.4 and 6.6% kernel rot. Increasing the sample size to 400 grams reduced the size of a significant difference to 1.22 or only 0.36 below the figure for the 200-gram samples.

[3]Arny, A. C., and Dorchester, C. S. Methods of making determinations and interpreting results in grain grading. Jour. Amer. Soc. Agron., 16:488–506. 1924.

TABLE 2.—*Statistical measurements used in analysis of data on variability in sampling lots of shelled corn for kernel rot determinations, data for samples with 5% kernel rot.*

Size of sample, grams	No. determinations	Mean %	Standard deviation			Size of differences for the level of significance indicated		Determination within the 5% limits %
			Individual groups %	Average %	Mathematical expectation %	5%	1%	
25	16	6.06	1.62	1.64±.29	1.64	4.64	5.97	42.2
25	16	—	1.51	—	—	—	—	—
25	16	—	1.84	—	—	—	—	—
25	16	—	1.59	—	—	—	—	—
50	16	5.12	1.20	1.06±.19	1.16	3.00	3.86	84.4
50	16	—	0.92	—	—	—	—	—
100	16	5.10	0.82	0.82±.14	0.82	2.32	2.99	87.5
200	16	5.06	0.56	0.56±.10	0.58	1.58	2.04	93.7
400	16	5.03	0.43	0.43±.08	0.42	1.22	1.57	100.0

In the last column in Table 2 are recorded the percentage of kernel rot determinations which actually fell within the limits of ± a significant difference (5% point) from the mean of the 400-gram samples,

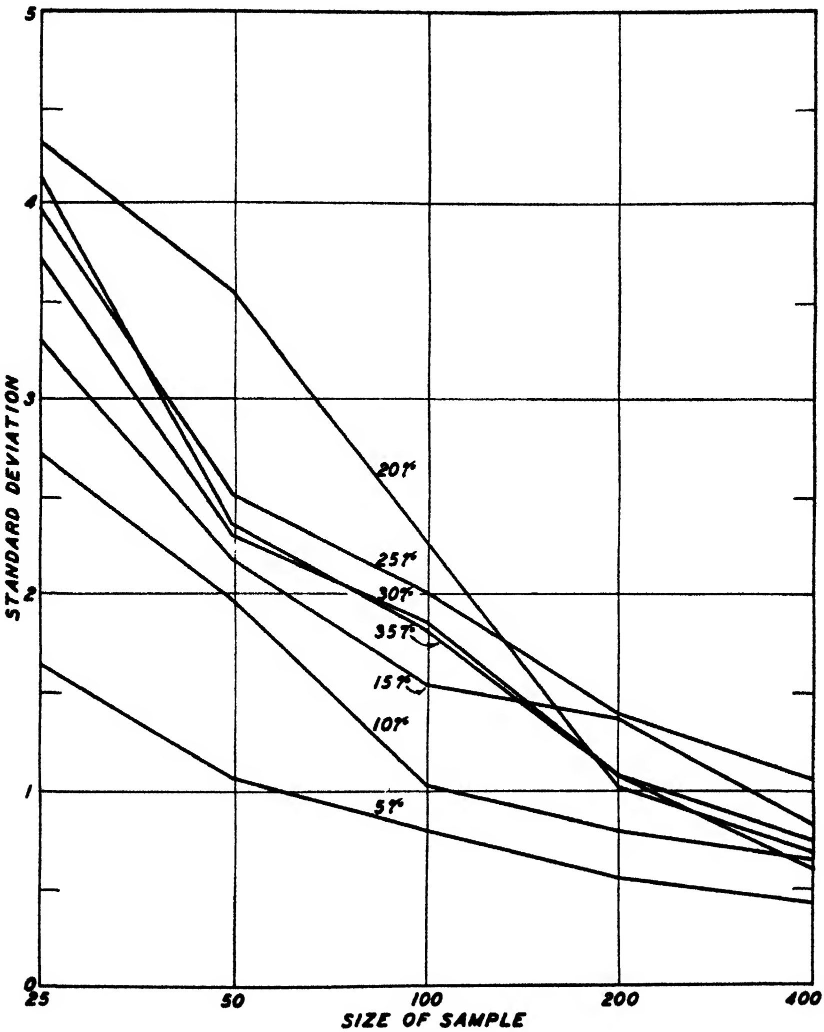

Fig. 4.—Standard deviation as influenced by size of sample and percentage of kernel rot.

that is between the limits of 5.03 ± 1.22. It is seen that 93.7% of the 200-gram determinations came within these limits. The relatively high percentage for the 50-gram samples is not so representative of the results obtained for samples of this size from the lots of grain containing higher percentages of kernel rots (Fig. 5).

The percentage of the determinations for the various sample sizes and for all disease levels which fell within the limits of ± a significant difference (5% point) from the mean of the 400-gram samples from the same disease level are shown graphically in Fig. 5. These curves emphasize the inadequacy of the small samples in determinations on

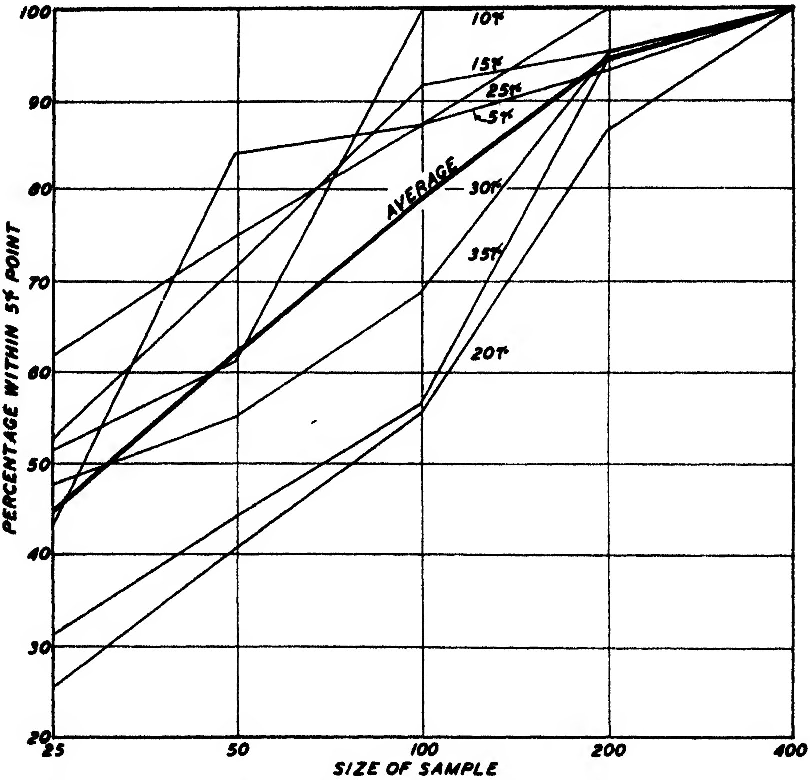

FIG. 5.—Percentage of the determinations for the samples of various sizes and for all disease levels studied which fell within the limits of ± a significant difference (5% point) from the mean of the 400-gram samples from the same disease level.

those lots with the higher levels of disease. The data for the average of all determinations show that 44.9% of the 25-gram samples, 62.0% of the 50-gram samples, 79.4% of the 100-gram samples, 94.6% of the 200-gram samples, and all of the 400-gram samples fall within the limits mentioned. By this standard of comparison, then, the 200-gram samples were in 95% of the cases as efficient as the determinations made on 400-gram samples.

SUMMARY AND CONCLUSIONS

The data presented pertain to problems met in determining relative amounts of ear rot in strains of corn. The first study involved methods

of measuring ear rot in field samples. The percentage of ears rotted was determined by count in each of 37 hybrids and varieties from 50-hill populations, or approximately 125 ears for each entry. The percentage of rotted kernels in the shelled grain from the same samples then was determined, using 200- to 300-gram samples for analysis. A comparison of the results from the two methods of determining ear rot in these identical samples showed the ear separation method to have given very inaccurate results, the coefficient of correlation between the two methods being only + 0.40. A modification of the ear separation method involving the determination of the percentage of rot by weight gave more efficient results as indicated by a coefficient of correlation of + 0.62. In the latter method the completely rotted ears and the rotted portions only of the partly rotted ears were included in the rotted separate. Bleached and otherwise doubtful looking ears were broken to determine whether they were internally rotted. The results from the experiments illustrate the difficulty of measuring accurately the amount of ear rot on a basis other than by the kernel separation method.

Data are presented which show the advantages of delaying the harvest of material where ear-rot determinations are to be made. Harvestings in December not only ran considerably higher in ear rot than those made in October, but the differentials between resistant and susceptible strains were widened in the later harvestings.

Studies are reported which deal with a statistical analysis of the variability encountered in sampling lots of shelled corn. These studies were made on lots containing 5, 10, 15, 20, 25, 30, and 35% of rotted kernels by weight. A 1,600-gram sample of the lot representing each disease level was divided into samples of approximately 25 grams by means of successive divisions through a Boerner divider. After making kernel rot determinations on each of the 25-gram samples, the percentage of rot for samples of 50, 100, 200, and the 400 grams was computed by combining the data from a sufficient number of randomly chosen 25-gram samples. Variability was measured in terms of the standard deviation, and the proportion of the determinations falling within the limits of ± a significant difference (5% point) from the mean of the 400-gram samples of the same disease level was used as a means of determining the relative efficiency at the various sample sizes. The results showed a general tendency for the standard deviation to increase as the percentage of kernel rot in the samples increased. Averages of all determinations for each sample size showed the following percentages of the samples to fall within the limits of ± a significant difference (5% point) from the mean of the 400-gram samples from the same disease level: 25 grams, 44.9%; 50 grams, 62.0%; 100 grams, 79.4%; 200 grams, 94.6%; and 400 grams, 100%.

Thus, according to this standard for comparison, the determinations on the 200-gram samples were in 95% of the cases as accurate as the results obtained from 400-gram samples.

COTTON ROOT-ROT AND WEEDS IN NATIVE HAY MEADOWS OF CENTRAL TEXAS[1]

C. H. ROGERS[2]

KEEPING an area free of susceptible plants for a period of 3 or more years is one of the most practical means of combating the cotton root-rot disease and lowering the viability of the root-rot fungus *Phymatotrichum omnivorum* (Shear) Duggar in infested areas of the central Texas blacklands.

The disease is spread by mycelial strands growing along infected roots or freely through the soil to adjacent or nearby roots of susceptible plants. It is maintained or carried over from season to season by these infected roots with strands and also by sclerotia. Sclerotia are formed as swellings in the strands throughout the heavy clay soils to a depth of 3 or 4 feet. They are brown in color when mature and vary from less than a millimeter to around a centimeter in size. Results so far have shown that sclerotia retain a viability of 10% or greater (1, 2, 4, 5)[3] after a period of 6 years. They are, therefore, doubly important in the rôle of perpetuating the disease in that they serve as well as or better than infected roots in a season-to-season carry-over and, in addition, may maintain the disease in an inactive state for a period of years.

Due to the fact that no grasses are susceptible to root-rot, meadows as well as permanent and semi-permanent pastures would serve to starve out and prevent the spread of the root-rot fungus if kept in a pure stand of grass. At the same time higher yields of better quality hay and more protection for the highly erosive clay soils would be obtained.

During the last 4 years, plants have been found dying from root-rot in areas that have never been cultivated, both in meadows and in woods. Except in one case (6), on a railroad right of way, no sclerotia have been reported found in areas that have never been cultivated. No viability tests were recorded in this instance.

In May, 1935, permission was obtained from the owner to take soil samples for sclerotial analysis from a meadow in the western edge of Falls County, Texas, that had a number of weeds dying from root-rot. The area, about 10 acres in size, had never been cultivated.

METHODS

A total of 180 samples for sclerotial analysis were taken to a depth of 3 feet with a 7-inch post hole auger. The first, second, and third foot were kept separate so that some idea could be obtained as to the vertical distribution of sclerotia in the soil.

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[1]Contribution from the Division of Plant Pathology and Physiology, Texas Agricultural Experiment Station, College Station, Tex. Received for publication August 3, 1936.

[2]Plant Pathologist, Substation No. 5, Temple, Tex. The writer is indebted to S. E. Wolff for aid in identifying the plants given in this paper.

[3]Figures in parenthesis refer to "Literature Cited," p. 823.

The samples were taken at various points over the meadow, usually near dead or dying prairie parsley (*Pleiotaenia nuttalli*) plants.

Twelve post hole samples were taken at each location and grouped in one composite sample. Sclerotia were separated from the soil by methods previously described (3). Viability tests of sclerotia were made by germinating on moist filter paper in sterile petri dishes.

A detailed survey was made of all plant species present in the meadow at the time of sampling.

SCLEROTIAL STUDIES

Sclerotia were found in approximately 60% of the samples from various places over the meadow. Results of the sampling and viability tests are given in Table 1. As in other studies, made in infested cultivated fields, most of the sclerotia were found in the second and third foot depths.

TABLE 1.—*Number and viability of root-rot sclerotia from an uncultivated meadow.*

Depth, ft.	No. of sclerotia	No. viable sclerotia	Percentage viable
1	91	79	86.8
2	362	328	90.6
3	485	451	93.0
Totals..........	938	858	91.5

Although large quantities of sclerotia from various areas have been tested, these had a higher average viability than a like average from any other area sampled thus far. The highest viability previously found was 66.3% in a thoroughly infested area planted continuously to cotton since 1927. Sclerotia are of a light amber or light tan color when first formed. With increase in age they usually become darker, although environmental conditions, such as moisture, temperature, and exposure to air also affect the color. These sclerotia were, for the most part, of a light color and apparently recently formed. It is possible, however, that in an undisturbed area with a permanent plant covering, the appearance and viability would be more uniform and lasting.

Pure cultures of the root-rot fungus were obtained from sclerotia from seven different samples. All cultures were very vigorous and reproduced sclerotia in abundance. These original isolations had a few noticeable differences as compared to similar isolations obtained from sclerotia found in various cultivated areas. The mycelial strands were, when first formed, cord-like and free of the typical acicular or needle-like short branches, that are ordinarily formed as the strands become developed.

PLANT SPECIES

A total of 47 different species of plants were found in the meadow at the time of sampling. Of the 47 species, 7 were grasses, 3 non-root-rot-susceptible weeds,[4] and 37 root-rot-susceptible weeds. A list of these plants follows:

[4]All plants other than grasses are referred to as weeds.

Non-susceptible Plants

1. Grasses:	Big bluestem,	*Andropogon furcatus*
	Little bluestem,	*Andropogon scoparius*
	Rescue grass,	*Bromus catharticus*
	Little barley,	*Hordeum pusillum*
	Limnodea,	*Limnodea arkansana*
	Dropseed,	*Sporobolus asper* var. *Hookeri*
	Texas needlegrass,	*Stipa leucotricha*
2. Weeds:	Horsemint,	*Monarda dispersa*
	Wild iris,	*Nemastylis acuta*
	Blue eyed grass,	*Sisyrinchium* sp.

Susceptible Plants

Mimosa,	*Acaciella hirta*
Umbrella-wort,	*Allionia lanceolata*
Giant ragweed,	*Ambrosia aptera*
Milkweed,	*Asclepiodora viridis*
Aster,	*Aster multiflorus*
Milk vetch,	*Astragalus nuttallianus*
Bifora,	*Bifora americana*
Wine cup,	*Callirrhoe digitata*
Thistle,	*Cirsium* sp.
Wild carrot,	*Daucus pusillus*
Larkspur,	*Delphinium albescens*
Engelmann's daisy,	*Engelmannia pinnatifida*
Indian blanket	*Gaillardia pulchella*
Fragrant gaillardia,	*Gaillardia suavis*
Wild geranium,	*Geranium carolinianum*
Hymenopappus,	*Hymenopappus robustus*
Dwarf dandelion,	*Krigia occidentalis*
Vetchling,	*Lathyrus pusillus*
Cone flower,	*Lepachys columnifera*
Pepper grass,	*Lepidium virginicum*
Bladder-pod,	*Lesquerella polyantha*
Button snakeroot,	*Liatris punctata*
Texas star,	*Lindheimera texana*
Bluebonnet,	*Lupinus texensis*
Sensitive briar,	*Morongia angustata*
Mesquite,	*Neltuma glandulosa*
Yellow sensitive briar,	*Neptunia lutea*
Primrose	*Oenothera missouriensis*
Ground cherry,	*Physalis mollis*
Plantain,	*Plantago rhodosperma*
Big parsley,	*Pleiotaenia nuttalli*
Ragwort,	*Senecio glabellus*
False dandelion,	*Sitilias multicaulis*
Horse-nettle,	*Solanum carolinense*
Purple nightshade,	*Solanum elaeagnifolium*
Stinging nettle,	*Tragia nepetaefolia*
Leavenworth vetch,	*Vicia leavenworthii*

Although all of the seven grasses are of some value as forage, the two species of Andropogon are most important, especially from the standpoint of hay production.

Many of the susceptible plants, as well as some not listed, have been found dying from root-rot in other undisturbed prairie meadows. In one large meadow of about 400 acres in the northern part of the Blackland belt near Greenville, Texas, numerous spots of infection were found by S. E. Wolff and the writer in the early fall of 1931. In this case those plants most readily observed as infected or dying with root-rot were two species of sunflower (*Helianthus maximilianni* and *H. annus*), green milkweed (*Asclepiodora viridis*), tall goldenrod (*Solidago altissima*), perennial ragweed (*Ambrosia psilostachys*), white-wreath aster (*aster multiflorus*), and spurge nettle (*Tragia* sp.). Extensive sampling for sclerotia has been made only in the one meadow given above.

A large number of the weeds found in meadows and pastures in central Texas are more or less poisonous. Some of those in the above lists that have stock-poisoning qualities are the milkweeds, ragweeds, larkspur, bluebonnet, ground cherry, spurge nettle, and the species of Solanums.

SUMMARY

The root-rot fungus *Phymatotrichum omnivorum* has repeatedly been found infecting and killing plants in undisturbed Texas blackland prairies.

Sclerotia, the carry-over stage of the root-rot fungus, of extremely high viability were found at 1-, 2-, and 3-foot depths in the soil in an undisturbed meadow.

Of a total of 47 plant species present in the meadow, 37 were susceptible to a greater or lesser degree to the root-rot fungus.

Additional susceptible plants were found in nearby meadows and in other meadows in other parts of the blackland belt.

Meadows and pastures should be kept free of weeds not only to starve out the root-rot fungus, but also to produce a hay of better quality and to secure a thorough covering of grass for better combating soil erosion.

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RESPONSE OF PLANTS TO BORON, COPPER, AND MANGANESE[1]

R. J. MUCKENHIRN[2]

THE importance in plant growth of a number of elements other than the 10 usually considered necessary is now generally recognized. Boron, copper, and manganese are three of the most noteworthy of these so-called "minor" elements. A great number of investigations support the contention that green plants are unable to grow normally without them (38)[3]. The experiments described in this paper deal with the action of boron, copper, and manganese in promoting the growth and development of plants in the field and greenhouse.

REVIEW OF LITERATURE

Boron.—The essential nature of boron was demonstrated by Brenchley and Warington (6) for certain legumes; by Haas and Klotz (15) for citrus cuttings; by Johnston and Fisher (19) and Van Schreven (37) for tomatoes; by McHargue and Calfee (26) for lettuce; by Scharrer and Schrop (32) and Belousov (4) for sugar beets and turnips; by Martin (24) for sugar cane; and by Van Schreven (36) for tobacco. Agulhon (1), McMurtrey (28), and others have shown that the addition of boron sometimes results in increased growth of a variety of crops in the field.

The symptoms of boron deficiency usually reported are depressed growth, distorted leaves, death of terminal buds, heart-rot in beets, a break down of the meristematic tissues, and an increase in starch and sugar in the leaves, presumably because disintegration of the phloem prevents translocation.

Copper.—Improvements in the productivity of peat and muck soils by the addition of copper have been reported in Florida by Allison, Bryan, and Hunter (2); in New York by Felix (12); in Michigan by Harmer (16); and in Indiana by Conner (9). Densch and Hunnius (11) found that copper fertilization increased the chlorophyll content of crops; Knott (20) reports that it improves the color and thickness of onion scales; Mader and Blodgett (23) state that copper sprays reduce potato scab; and Coleman and Ruprecht (8) agree with other investigators that it increases the copper content of the plants. The majority of the workers quoted found that the beneficial effect is obtained whether the copper salts are sprayed on the leaves or applied to the soil.

Sommer (35) and Lipman and MacKinney (22) found that, in solution cultures of highly purified material, minute amounts of copper are needed for the normal growth of a number of the crop plants. Anderssen (3) found from chemical analyses that chlorotic leaves of fruit trees grown on a sandy soil were low in copper. The application of copper to the soil or leaves of the trees cured the chlorosis.

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. A portion of a thesis submitted to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication August 3, 1936.

[2]Instructor in Soils. The writer wishes to express his appreciation for the helpful suggestions and criticisms tendered by Professor E. Truog under whose general direction this work was done.

[3]Figures in parenthesis refer to "Literature Cited", p. 841.

Manganese.—McHargue (25) and McHargue and Calfee (26) showed that many crop plants fail to grow normally if manganese is excluded from the culture medium. Samuel and Piper (31) obtained similar results with grains, Haas (14) with citrus cuttings, and Hopkins (18) with aquatic plants. The work of Conner (9), Davies and Jones (10), Gilbert (13), Hoffman (17), Lee and McHargue (21), Miller (30), Schreiner and Dawson (33), and many others shows that many soils do not supply sufficient manganese. However, Carlyle (7) found that only 1 of 21 Texas soils responded to manganese fertilization and that upland soils usually contain adequate amounts of available manganese.

BORON NEEDS OF LETTUCE

The first part of this investigation deals with the influence of boron and other elements on the growth of leaf lettuce in quartz sand cultures. Salts of the elements and materials containing one or more of them, such as Milorganite, kaolin, and Pyrex glass, were added to the pots in addition to the usual nutrient elements.

FIRST EXPERIMENT WITH LETTUCE

Plan of pot culture.—Grand Rapids Forcing House leaf lettuce was grown in carefully selected and washed 2-gallon glazed earthenware jars, each filled with 13 kilograms of a white quartz sand low in impurities but not artificially purified. The sand was maintained at a moisture content of 13% by additions of distilled water.

The basal nutrient treatment per pot, made of the purest chemicals available, consisted of the following:

$FePO_4$	2.00 grams
$CaHPO_4.2H_2O$	1.00 gram
KNO_3	1.08 grams
$Ca(NO_3)_2.4H_2O$	0.50 gram
$MgSO_4.7H_2O$	0.50 gram
NaCl	0.01 gram

The $FePO_4$ and $CaHPO_4.2H_2O$, in powdered form, were mixed with the sand. The other salts were applied in solution. The minor elements, either singly or in combination, were applied in solution in the following amounts per pot to some of the pots:

$MnSO_4.4H_2O$	16.0 mg
NaI	2.0 mg
H_3BO_3	5.7 mg
$Al_2(SO_4)_3.18H_2O$	25.0 mg

Powdered CuO was mixed with the sand of some pots at the rate of 0.385 gram per pot. Milorganite was added to some of the pots at the rate of 7.7 grams per pot, equivalent to 1 ton per acre, with and without the basal nutrients. One hundred grams of kaolin and the regular basal nutrients were added to one of the pots. All but this kaolin treatment were duplicated.

Planting was made February 19, 1934, and after about 3 weeks the plants were thinned to eight per pot. On April 16 the leaves were removed and 1 gram per pot of KNO_3 in solution was added. On May 31, 0.5 gram of NH_4NO_3 and on

June 15 0.5 gram of NH_4NO_3 plus 0.5 gram of KNO_3 were added to each pot. A second cutting of the leaves was made on June 27.

Results.—Boron appeared to improve the vigor of the plants and increased the yield slightly. The effect of the other elements was negligible. Kaolin gave a marked increase in yield.

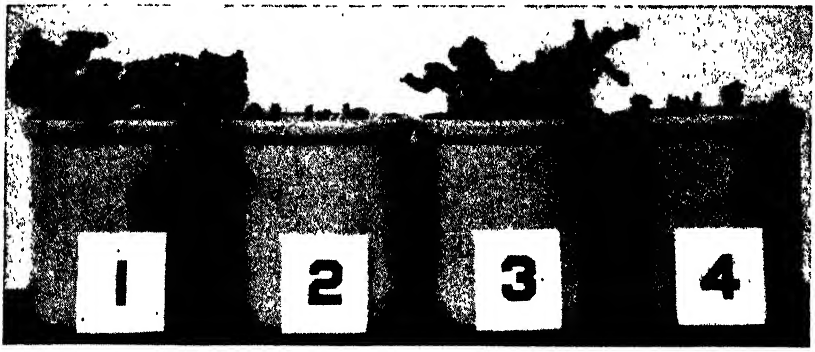

FIG. 1.—The effect of boron on the second growth of lettuce leaves. 1, basal nutrients, Mn, I, Cu, with boron; 2, basal nutrients, Mn, I, Cu, without boron; 3, basal nutrients, Mn, I, Cu, Al, with boron; 4, basal nutrients, Mn, I, without boron.

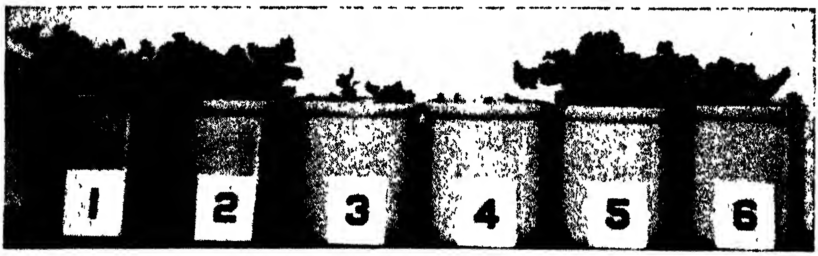

FIG. 2.—Comparison of the effects of Milorganite and boron on the second growth of lettuce leaves. 1 and 2, basal nutrients, Mn, I, Cu, with boron; 3 and 4, basal nutrients, Mn, I, Cu, without boron; 5 and 6, basal nutrients, Mn, I, with Milorganite. Eight days before this picture was taken, 5 mgs of H_3BO_3 were added to No. 3. The re-growth of leaves has already begun.

One week after the first leaves had been removed, only the plants in the pots which had received boron or Milorganite had sprouted new leaves. To test the relation of boron to the production of new leaves, one of the duplicates from each of three treatments was given 5 mg. of H_3BO_3 in solution on April 26. The pots so treated were: (A) Control, basal nutrients only; (B) basal nutrients plus Mn and I; and (C) basal nutrients plus Mn, I, and Cu. On May 3, the plants in these pots had begun to sprout new leaves, but those in the duplicates did not (Figs. 1 and 2). The plants receiving boron or Milorganite continued growth and produced flowers and seed heads. The others did not produce second leaves and died within 2 or 3 weeks. The

plants supplied with Milorganite showed boron deficiency symptoms to some extent, but they grew to maturity. The boric acid treatments produced entirely normal plants.

SECOND EXPERIMENT WITH LETTUCE

Plan of pot cultures.—The pots and basal nutrients used were the same as those of the first experiment, except that small amounts of treated kaolin, silicic acid, or Miami silt loam were added to some of the pots.

The marked stimulation of growth (first cutting) from kaolin treatment in the first experiment led to an investigation of the possible effects of the impurities in the kaolin. Samples of kaolin were digested with hydrochloric acid to remove impurities, such as manganese, which might be present, or with sodium carbonate to remove free silica. The effect of these kaolins when added to quartz sand cultures was then compared with that of pure silicic acid and Miami silt loam.

This experiment was begun before the need of boron for the second growth of leaves had been revealed by the first experiment, and none of the pots in the second experiment were supplied with boron. The deficiency made itself evident after the first harvest of leaves.

Results.—The weights of the first leaves showed that the kaolin increased the growth of the lettuce. The Miami silt loam increased the weight of green leaves but not that of the dry leaves.

On May 22, 8 days after cutting, none of the plants except those supplied with soil had begun to produce a second growth of leaves, so 7 mg. of H_3BO_3 were added to each of five pots. In a few days all the plants in these pots sprouted new leaves which continued normal growth, while the plants in the remaining pots did not continue growth except where 200 grams of Miami silt loam had been added. This amount of soil furnished enough boron to allow about one-half of normal growth, but the leaves produced were thick, contorted, lumpy, and lower in dry matter than the normal leaves from the boron-treated pots. These results confirmed those of the first experiment in every way.

THIRD EXPERIMENT WITH LETTUCE

Plan of pot cultures.—The need for boron became strikingly evident in the first two experiments soon after the first leaves were removed from the lettuce. A third experiment was begun to determine if the boron deficiency could be demonstrated without cutting off the leaves.

Each of six pots was supplied with the same amounts of sand and basal nutrients as were used in the first experiment. Two of the six pots received no boron, two received 10 mg of H_3BO_3 in solution, and each of the remaining two received 135 grams of ground Pyrex glass. McHargue and Calfee (27) have reported that Pyrex glass, which contains about 11% of B_2O_3, is an excellent source of boron for plants. Lettuce was planted in the pots on February 22, 1935, and allowed to grow to maturity under the same conditions as had obtained in the preceding experiments.

Results.—Two and one-half months after planting evidences of boron deficiency showed up clearly in the pots receiving neither boric acid or Pyrex glass. The inner leaves of these plants were lumpy and contorted, their edges were curled inward or outward, and they

lacked the wavy outline found on healthy leaves. All the leaves were mottled and edged with yellowish areas and the growing points were thickened and deformed. The plants supplied with boric acid had healthy, crisp, wavy-edged leaves and normal growing points. Those supplied with Pyrex glass, however, were even darker green, larger, and more vigorous, thus indicating that Pyrex glass furnishes boron in a particularly suitable form. After the appearance of these results one of the no-boron pots was treated with 10 mg of H_3BO_3. This soon caused the plants to produce new, healthy leaves, and, after a month they were perfectly normal. The old, abnormal leaves died and were replaced by new leaves from the leaf axils.

DISCUSSION

Boron in minute amounts in necessary for the growth of lettuce. The quartz sand used was so low in boron content that the need could be demonstrated without further purification of the sand. Boron is concerned directly with the physiology of the plant since specific disorders result from a lack of this element.

The plants were analyzed for boron by means of the turmeric paper test described by Bertrand and Agulhon (5). The dry leaves of the plants receiving boric acid contained about 20 p.p.m. of boron, while the first leaves of the boron-deficient plants contained about 10 p.p.m. The plants treated with Milorganite had a variable content which was intermediate between the above values. The boron content of Milorganite is about 0.004%, and not all the plants treated with it were able to produce a normal second growth of leaves.

The evidences of boron deficiency in lettuce are easily recognizable and are similar to the disorders of other plants inadequately supplied with boron. The deformation and death of the growing point and meristematic tissue, and the thickening, crumpling, and curling of the leaves are characteristic. In Fig. 3, pots 2 and 3 illustrate the yellowed and spotted appearance of the leaves of boron-deficient

FIG. 3.—Pyrex glass as a source of boron for lettuce. 1, basal nutrients with pyrex glass; 2 and 3, basal nutrients without pyrex glass. No. 2 was later treated with 10 mgs of H_3BO_3, after which it produced a vigorous growth of normal leaves.

plants. In some cases where the leaves were removed and boron was not added, small, deformed leaves appeared, but they did not continue to grow and did not recover entirely even after boron was added. New leaves produced from leaf axils which had not begun growth previously enabled the plant as a whole to regain normal growth. A deficiency of boron in lettuce reveals itself quickly by sharp contrast between healthy and deficient plants, especially if the first leaves are removed when full grown.

INFLUENCE OF KAOLIN AND OTHER MATERIALS ON GROWTH OF BUCKWHEAT

Experiments by Meyer (29) showed that the addition of kaolin to quartz sand cultures was beneficial to the growth of buckwheat, alfalfa, and oats, and that the addition of manganese to these cultures gave consistently favorable results with buckwheat. Meyer concluded that manganese supplied by the kaolin accounted, at least partly, for the kaolin's beneficial effect. This subject was studied in the experiments that follow.

PLAN OF POT CULTURES

Buckwheat was grown in pots to which were added the same materials and nutrient salts as in the experiments with lettuce. Kaolin from South Carolina, Pennsylvania, and Georgia was used at the rate of 50 or 100 grams per pot. The South Carolina kaolin was used in the natural state and also after treatment either with HCl to remove manganese and other acid-soluble impurities or with Na_2CO_3 to remove colloidal silica. In the HCl treatment, 80-mesh material was digested on a steam hot plate for 48 hours in 0.2 N hydrochloric acid and then washed with water slightly acidified with HCl. In the Na_2CO_3 treatment, another portion was digested for 16 hours on a steam plate in a 2% solution of sodium carbonate and then washed free of carbonates.

Silicic acid was added to one of the pots to determine it it would stimulate growth in a manner similar to kaolin. This material was prepared by treating sodium silicate (water glass) with hydrochloric acid and then filtering off the silicic acid and washing it free of chlorides.

Small amounts of Miami silt loam (100 and 200 grams), air dried, and ground to pass an 80-mesh sieve, were added to the sand in some pots to compare the effect of soil with that of kaolin on the growth of plants.

Two tests in duplicate were made, the first with untreated kaolin and the second with kaolin digested with acid or sodium carbonate. The first test was begun on February 19 and the second on March 16. The crop in the first test was harvested on April 16 and that in the second on May 14.

GROWTH AND YIELDS

The plants from one of the four controls (No. 3) gave an exceptionally high yield (19.2 grams) and had an unusually high content of manganese (316 p.p.m.) in their leaves. This yield and high manganese content were probably due to contamination from some unknown source, and hence, the remaining three controls probably serve better as a basis of comparison (Table 1). These three produced an average of 11.9 grams of dry tops per pot, as compared to

13.7 grams for all four controls and 18.4 grams for all kaolin treatments. The kaolin-treated plants had tall, thick stems, sometimes with abnormal swellings, and most of them had aborted seed heads and dead flowers, whereas the plants receiving basal nutrients only produced seed abundantly.

TABLE 1.—*Effect of kaolin and of soil in quartz sand cultures on the growth and manganese content of buckwheat.*

Treatment, basal nutrients common to all pots	Weight of dry tops, grams	Manganese content of dry leaves, p.p.m.	Manganese content of dry stems, p.p.m.	Estimated total manganese content of leaves, mg
1. Three controls not receiving kaolin (not including No. 3)	11.9	203	32	1.21
2. Four controls not receiving kaolin (including No. 3) ...	13.7	231	33	1.67
3. Four pots receiving untreated kaolin....................	18.8	347	40	3.26
4. Four pots receiving HCl-treated kaolin........ ..	18.3	289	45	2.66
5. Two pots receiving Na_2CO_3-treated kaolin..	18.2	197	37	1.80
6. Four pots receiving Miami silt loam.....	21.4	235	—	2.51
7. Two pots receiving Mn and I	15.0	296	—	2.25

The silicic acid apparently produced no changes in the plants. The yields of tops on pots receiving Milorganite or Miami silt loam were equal to, or even greater than, those produced by kaolin treatment. The use of Cu, I, Zn, B, and Al gave no benefit over the basal nutrients only, but Mn plus I gave an average yield increase of one-fourth.

MANGANESE CONTENT OF BUCKWHEAT AND KAOLIN

Meyer (29) concluded that the stimulation produced by kaolin in quartz cultures was at least partly due to an increase in the manganese supply brought about by manganese in the kaolin. The leaves and stems of the plants grown in the experiments just described were analyzed for manganese to determine whether a relation existed between kaolin treatment and the manganese content of the tissue.

The procedure followed was a modification of the periodate colorimetric method (34). One or 2 grams of dry tissue were ashed in a porcelain crucible over a low flame of a Meeker burner. The ash was dissolved in hot dilute nitric acid, the solution filtered and then evaporated to dryness. After any remaining organic matter was oxidized with H_2O_2, the residue was dissolved in HNO_3 and H_2SO_4 and the permanganate color developed in the usual manner. The leaves and stems from each pot were analyzed separately.

The weight of the dry leaves as distinguished from that of the stems and seeds was not determined, but was estimated as one-half the weight of the tops.

The results of the analyses, given in Table 1, show that increased growth is associated with a high content of manganese in the leaves. The kaolin treatment increased the weight of the tops almost 70%, the total manganese content of the leaves about 120%, and the manganese content of the stems from 30 to 50%. The Miami silt loam increased the yields of dry matter somewhat more than the kaolin, but it resulted in a smaller increase in the manganese content of the leaves. The Mn and I treatment increased the yields about 25% and the total manganese content of the leaves almost 80%. The stems of the kaolin-treated plants had not only a higher concentration of manganese but also a greater weight.

The plants in the pots receiving 100 or 200 grams of Miami silt loam probably had more favorable conditions for growth since they produced the largest dry weights, but they had a low concentration of manganese in their leaves. With the exception of these plants, those producing the greatest dry weight had aborted seed heads and dead flowers. Besides the plants supplied with soil, only those in the two lowest-yielding controls and those treated with silicic acid produced healthy seeds in abundance, and all of these plants had a comparatively low concentration of manganese in the leaves.

To determine whether or not the kaolin supplied the manganese found in the plants, duplicate 5-gram samples of both the untreated and the Na_2CO_3 treated material were digested over night on a steam hot plate at 85° C in 100 cc of either 1 N or 0.005 N H_2SO_4. Repeated attempts failed to detect a trace of manganese in the acid extracts of this kaolin.

Samples of the quartz sand were similarly treated. One normal H_2SO_4 extracted an average of 20.2 p.p.m. of manganese from the sand and 0.005 N H_2SO_4 extracted, without heating, 4 p.p.m. Thus, each pot contained 52 mgs of manganese soluble in cold 0.005 N H_2SO_4 and 260 mgs soluble in hot 1 N H_2SO_4, while hot 1 N H_2SO_4 would extract no appreciable amount of manganese from the kaolin of which no more than 100 grams was present in any one pot. The kaolin did not supply manganese directly, but it enabled the roots to extract more manganese from the sand. An application of 50 grams of HCl-leached kaolin had almost as great an effect on growth and manganese content as one of 100 grams.

DISCUSSION

These experiments tend to support Meyer's conclusion that buckwheat responds to additions of manganese in these quartz sands. The correlation between yield and manganese content of the leaves is close and it suggests, although it does not prove, that the former is dependent on the latter. The stimulation produced by kaolin in these quartz sand cultures is related to an improvement in the feeding power of the roots upon manganese and possibly upon other elements present in the sand or added in solution. The abnormalities in the stems and the failure to produce seed suggest that the kaolin-treated plants actually had an excess of manganese and that the stimulation of growth was abnormal.

GREENHOUSE EXPERIMENTS WITH COPPER AND MANGANESE ON PEATS

Observations made by James D. Swan, Jr., of the Turtle Valley Farms, indicated that onions made improved growth on areas of sedge peat on which potato sprays had been used the previous year. Greenhouse experiments with this peat were begun in May 1934 to test the use of copper and other elements. The peat in question, located in Walworth County about 5 miles north of Delavan, Wis., is low in mineral matter and has a pH of about 6.2. The tract was drained in 1925 and onions and potatoes have been grown on portions of it since that time. Commercial fertilizers have been applied annually in rather large amounts.

In a preliminary greenhouse test, B, Mn, I, Cu, and Zn were added to some of the pots in addition to phosphorus and potash at approximately the same rates as were used in the field. Two crops, lettuce and onions, were grown on peats from four different parts of the tract. The plants responded to the minor elements to some extent on all four peats, but especially on two on which the onions showed increases in growth of 36% and 42%, and the lettuce showed smaller increases. These peats were designated B and D, respectively, and extended experiments were next carried out with them.

FIRST EXPERIMENT

Plan of pot cultures.—Two-gallon pots were filled with 1,430 grams of peat B or with 1,670 grams of peat D, on a dry basis. Each pot received 0.80 gram KH_2PO_4, 0.90 gram K_2HPO_4, and 0.66 gram NH_4NO_3, which is the equivalent of 1,000 pounds per acre of a 6-20-20 fertilizer.

Salts of the minor elements were applied in the following amounts per pot, whether singly or in combination:

0.11 gram H_3BO_3 equivalent to 28.5 pounds H_3BO_3 per acre.
0.077 gram $Zn(NO_3)_2.6H_2O$ equivalent to 20 pounds per acre.
0.0252 gram KI equivalent to 6.5 pounds per acre.
0.231 gram $CuSO_4.5H_2O$ equivalent to 60 pounds per acre.
0.308 gram $MnSO_4.4H_2O$ equivalent to 80 pounds per acre.
0.770 gram NaCl equivalent to 200 pounds per acre.

The peats were maintained at a water content of about 260% by periodic additions of distilled water collected from a block tin condenser and then carried to the greenhouse in glass carboys.

Seeds of Yellow Globe Danvers onions were planted on July 17, 1934, and the onions were harvested on January 1, 1935. Artificial light was provided during the shorter days of the autumn.

The residual effect of the minor elements was determined by growing sweet clover on peat B after the onions were harvested. The equivalent of 1,000 pounds per acre of an 0-20-20 mixture was applied to each pot in the form of 0.6 gram of K_3PO_4 and 1.1 grams of KH_2PO_4 before planting inoculated sweet clover seeds on February 13, 1935. The plants were harvested at the end of 2 months.

Results with onions and sweet clover.—Table 2 gives the comparative weights of dry tissue of onions and sweet clover produced in this experiment. The onions treated with copper, manganese, or zinc

gave considerable improvements in yield on peat B but no response on peat D. The results with sweet clover on peat B were complicated by the fact that the pots which had given low yields of onions had a greater residue of unused fertilizer (P and K). In spite of this difference, which worked in favor of the controls, the copper and manganese treated pots yielded from 5 to 15% more.

TABLE 2.—*Comparative yields of onion bulbs and sweet clover on a dry weight basis on peats B and D in pot cultures with yield of controls represented by 100.*

Treatment	Comparative yield, av. of two pots		
	Peat B		Peat D
	Onion bulbs	Sweet clover†	Onion bulbs
No fertilizer	87	72	28
Control, 6–20–20 only, av. of 3*	100	100	100
Control, 6–20–20 only, av. of 2 highest	114	104	114
Copper and 6-20-20	176	105	97
Manganese and 6–20-20	158	108	80
Zinc and 6–20–20	161	102	102
Boron and 6–20–20	112	109	80
Iodine and 6–20–20	111	115	72
Cu, Mn, and 6–20–20	126	115	97
Cu, B, and 6–20–20	158	103	117
Mn, B, and 6–20–20	126	112	97
Cu, B, Mn, and 6-20–20	142	113	95
Cu, B, Mn, Zn, and 6–20–20	151	108	101
Cu, B, Mn, Zn, I, and 6-20-20	154	98	103
NaCl and 6–20–20	148	89	107

*The controls were planted in triplicate.
†Before planting the sweet clover, the equivalent of 1,000 lbs. per acre of an 0–20–20 fertilizer was added to each pot. The sweet clover was grown to test the residual effects of the minor elements which had been applied before the onions were planted.

The onions treated with copper, manganese, or zinc either singly or in combination had a greater weight of bulbs than of tops, while the reverse was true of the controls, of those receiving no fertilizer, and of those treated with boron or iodine. The plants on peat D were not benefitted by applications of the minor elements and in every case where the 6–20–20 was used a greater weight of bulbs than of tops was produced.

SECOND EXPERIMENT

The results from applications of copper, manganese, and zinc to peat B in the preceding experiments were so encouraging that a greenhouse experiment with five replications was set up using a peat similar in cropping history and productivity to peat B.

Plan of pot cultures.—Two-gallon pots were filled with 4,000 grams of peat having a moisture content of 146%. Seeds of Yellow Globe Danvers onions were planted on June 25, 1935. The equivalent of 1,000 pounds per acre of a 10–25–25 mixed fertilizer was added to each pot in the form of a solution of the following salts: 1.52 grams KH_2PO_4, 0.8 gram K_2SO_4, and 1.1 grams NH_4NO_3. On June

29 salts of the rarer elements were applied in solution, singly and in combination, in the following amounts per pot:

0.231 gram $CuSO_4.5H_2O$ equivalent to 60 pounds per acre.
0.084 gram $ZnSO_4.7H_2O$ equivalent to 19 pounds per acre.
0.280 gram $MnSO_4.XH_2O$ equivalent to 73 pounds per acre.

No artificial light was used as was done in the preceding experiment. The onions were harvested on December 3, 1935, when they had practically ceased growth. In cases where a "bottleneck" rather than a true bulb was formed, the lower 2 inches were taken as an approximation of the bulbs on these plants.

Results with onions.—The comparative yields of tops and bulbs (Table 3) show that a decided increase in growth followed the application of copper or manganese. The greatest increases are of tops which made up a higher proportion of the total weight than in the previous experiments, probably because of the reduced light supply. Copper produced the greatest increase in the weight of the tops, while manganese produced the greatest increase in the weight of the bulbs.

TABLE 3.—*Comparative pot culture yields of onion tops and bulbs on peat treated with copper, manganese, and zinc with yields of controls represented by 100.*

Treatment	Comparative yields, av. of 5 pots			
	Green tops	Dry tops	Green bulbs	Dry bulbs
No fertilizer	103	92	85	92
Control, 10–25–25 only	100	100	100	100
Copper and 10–25–25	130	122	117	108
Manganese and 10–25–25	112	106	134	135
Zinc and 10–25–25	121	112	105	106
Cu, Mn, and 10–25–25	110	116	110	102
Cu, Zn, and 10–25–25	103	108	98	88
Mn, Zn, and 10–25–25	98	109	88	79
Cu, Mn, Zn, and 10–25–25	125	118	110	102
NaCl and 10–25–25	111	111	98	85

The bulbs from plants receiving both copper and manganese resisted drying more than the others on account of the impervious skins which they had. After 7 weeks of drying at 70° C these bulbs had, on the average, 122% of water on the dry basis; the manganese-treated bulbs, 47% of water; and the control bulbs, 34%. The bulbs were finally cut into small pieces in order to bring the drying to completion. These observations as to the effects of copper and manganese on the ratio of bulbs to tops and on the nature of the skins suggest that further work would be likely to show that these elements affect the maturation of the plant as well as its rate of growth. The more impervious skins may be of considerable commercial value because of their protecting and preserving influence.

DISCUSSION

The data from the second experiment were treated statistically by the analysis of variance method. The copper, manganese, copper-

manganese, and copper-manganese-zinc treatments, considered as a group, gave a statistically significant increase in total weight of plants and weight of leaves over the pots receiving the 10–25–25 only. Furthermore, the increases produced by each of these treatments considered separately approach significance quite closely. When these results are considered in conjunction with those of the previous greenhouse experiments, with the field trials with onions and potatoes, and with observations made in the field, there is little doubt that these crops will respond to applications of copper and manganese on some Wisconsin peats.

The zinc, zinc-copper, zinc-manganese, and sodium chloride treatments did not show significant increases when compared with the controls. Zinc is evidently less effective than either copper or manganese in increasing yields on this peat.

That the sulfate carried by the copper and manganese salts did not cause the increase in yields is indicated by the following: The SO_4 present in the copper and manganese sulfates increased the amount supplied by the basal nutrient solution by only one-fifth to one-fourth. Moreover, the basal nutrients alone had only about one-third as much effect in increasing yields as the combination of basal nutrients with copper or manganese.

FIELD EXPERIMENTS WITH COPPER AND MANGANESE ON PEAT

A trial of copper in the field on the Turtle Valley peats was made in 1934 by James D. Swan, Jr., who described this experiment as follows: "We made the comparison with two sets of 15-row applications in different parts of the fields, in each case using 0–10–30 alone and 0–10–30 plus Cu in the adjoining rows, and in both fields we found a gain of approximately 22% in the number of crates of potatoes yielded where the Cu was added."

A field trial with copper, manganese, and zinc was carried out in 1935 by means of the machinery and methods regularly employed for large-scale production on these farms. The field chosen was the one from which peat had been taken for the second greenhouse experiment. It had been cropped about 10 years and was giving satisfactory yields. Onions and potatoes were grown as test crops.

EXPERIMENT WITH ONIONS

Plan of experiment.—The field was planted with Yellow Globe onions on April 20, 1935. The sulfates of copper, manganese, and zinc and commercial sodium chloride, mixed with a commercial 0–20–20 fertilizer, were applied in alternating 9-row strips, with a 9-row onion planter having a fertilizer attachment. The controls and strips treated with copper were replicated four times; the others three times. The amount of fertilizer applied was measured by subtracting the amount left in the planter after planting each series of strips from the amount placed in the planter at the start.

A measured length of 605 feet was harvested from the middle of the strips on September 9 leaving the two outer rows, so that each harvested plat consisted of 7 rows 605 feet in length. The total product of each plat was weighed. The onions from all plats having a given treatment were then combined and graded.

Results.—The results are given in Table 4. Unfortunately, thrip damage was serious on this field and early planting was disadvantageous in the 1935 season. The differences in yield due to treatment are insignificant except possibly in the case of manganese treatment, but there was a considerable improvement in the quality of the onions treated with copper. During the growing season the manganese-treated rows appeared to have larger and more vigorous tops, but no differences were apparent between the other treatments.

TABLE 4.—*Effect of applications of copper, manganese, zinc, and sodium chloride on the growth of onions on a peat soil in the field.*

Treatment on acre basis	Area harvested in acres	Total yield in bu. per acre	Yield of U. S. No. 1's in bu. per acre
Control, 346 lbs. of 0–20–20 only	0.454	497	408
192 lbs. 0–20–20 and 24 lbs. $CuSO_4 \cdot 5H_2O$	0.454	506	421
306 lbs. 0–20–20 and 38 lbs. $MnSO_4 \cdot XH_2O$	0.340	552	465
376 lbs. 0–20–20 and 24 lbs. $ZnSO_4 \cdot XH_2O$	0.340	505	418
320 lbs. 0–20–20 and 80 lbs. NaCl	0.340	457	Not determined

At the time of grading, the skins of the copper-treated onions peeled much less during handling and had a noticeably darker brownish or yellow color than the skins of onions receiving 0–20–20 only. The color, size, and appearance of the copper-treated onions were more uniform and their general quality was considered better by the graders. The manganese treatment increased the size of the onions but had little or no effect on quality, while the zinc treatment produced no appreciable improvement.

EXPERIMENT WITH POTATOES

Plan of experiment.—Copper sulfate, manganese sulfate, zinc sulfate, sulfur, and sodium chloride were mixed with a commercial fertilizer having the formula 0–20–20. On May 26, 1935, the potatoes (Cobblers) were planted in four-row strips with a two-row planter and fertilizer attachment; each strip of four rows receiving a given treatment. The strips were not replicated. The harvested portion of each strip had an area of 0.36 acre. The potatoes were harvested and weighed on September 15. Later all but the potatoes from the unfertilized rows were graded into two grades, commercial or unclassified.

Results.—The yields of tubers and the amounts of fertilizer used are given in Table 5. The copper, manganese, and zinc gave considerable increases in yield. The copper treatment produced tubers which were clearly superior in appearance and shape to those produced with other treatments, and the amount of scab seemed to be considerably reduced. The graders were of the opinion that the copper-fertilized potatoes could possibly have been graded as U. S. No. 1's, while those fertilized with 0–20–20 alone could not. The manganese, zinc, and sulfur treatments seemed to improve the quality somewhat over that of the controls, but the improvement was not nearly as great as with the copper treatment.

TABLE 5.—*Effect of copper, manganese, zinc, sulfur, and sodium chloride on the yield of potatoes on peat soil in the field.*

Treatment on acre basis	No fertilizer	327 lbs. 0-20-20 only	240 lbs 0-20-20 and 47 lbs. $CuSO_4.5H_2O$	254 lbs. 0-20-20 and 16 lbs. $ZnSO_4.XH_2O$	345 lbs. 0-20-20 and 42 lbs. $MnSO_4.XH_2O$	300 lbs. 0-20-20 and 300 lbs. sulfur	310 lbs. 0-20-20 and 77 lbs. NaCl
Total yield of plat, lbs.	4,664	4,975	5,951	6,241	6,204	6,033	5,616
Yield of commercial grade, 90-lb. sacks ...	—	—	43	50	51	5	—
Yield of unclassified grade, 90-lb. sacks...	—	42	9	—	—	48	—
Total yield, bu. per acre	214	230	274	288	285	277	258

DISCUSSION

Copper, manganese, and zinc gave increases in the yield of potatoes in this experiment similar to those obtained by Mr. Swan with copper in 1934. The improvement in color and appearance of the onions and potatoes following copper treatment is of appreciable commercial value, and the use of copper as a fertilizer on these peats might be justifiable for this reason alone. Manganese is of value in increasing growth on these peats, but it has less effect than copper on quality. Several Wisconsin farmers are now using copper sulfate as a fertilizer for truck crops, and recent reports suggest that further work might locate peats even more deficient in copper and manganese than those of the Turtle Valley area.

Chemical analysis of the fertilizers showed that the 0–20–20 used as base supplied about 35 pounds of sulfate per acre. The manganese sulfate supplied only 15 pounds and the copper sulfate, if pure, would have supplied only 6 pounds per acre. The increases noted, therefore, can hardly be ascribed to the sulfur in the copper and manganese sulfates since the 0–20–20 alone gave a comparatively small increase in yield over the unfertilized rows.

MANGANESE CONTENT OF PLANTS AND SOILS

The plants grown in the greenhouse and in the field were analyzed for manganese by the periodate method (34), modified as described in the discussion of the manganese content of kaolin and buckwheat. Each sample analyzed came from a single pot.

A method was developed for determining readily soluble manganese in soils in an attempt to distinguish between the peats which responded to manganese fertilization and those which did not. This method was then used in comparing the amounts of readily soluble manganese present in upland soils with that in these peats.

MANGANESE CONTENT OF PLANTS FROM POT EXPERIMENTS

Analysis of the bulbs gave practically the same content of manganese for all the treatments. Later analyses of onions indicated, however, that marked differences would be found only in the skins which should be analyzed separately, so the above result is inconclusive.

The leaves of onions grown on peat B fertilized with manganese contained a higher concentration of manganese than those not thus fertilized. This was not true with the onions grown on peat D. It will be recalled that manganese fertilization increased the yield in the former case but not in the latter. Manganese fertilization of peat B had an appreciable residual effect in increasing the manganese content of sweet clover grown as a second crop. The manganese content of the manganese-fertilized plants from the second greenhouse experiment was slightly, but perhaps not significantly, higher than that of plants not so treated, but the total amount of manganese removed by the manganese-fertilized plants was 21% greater.

MANGANESE CONTENT OF CROPS FROM FIELD EXPERIMENT

Samples of the onions and potatoes grown in the field experiment were analyzed. The potatoes were peeled and the skins and tubers dried and analyzed separately. The onions were divided into three parts, *viz.*, the skins or scales; the outer layers, consisting of the two or three outer leaves of the bulbs; and the remainder or interior of the bulb, referred to as the inner bulb. These parts were dried and analyzed separately. The results of the analyses, given in Table 6, show that the manganese treatment in the field produced a higher concentration of manganese in the skins of the onions and potatoes but not in the interior of the bulbs and tubers.

TABLE 6.—*Manganese content of onion bulbs and potato tubers from field experiment.*

Crop	Treatment	Av. manganese content of dry skins, p.p.m.	Av. manganese content of dried outer layers, p.p.m.	Av. manganese content of dried inner bulbs or tubers, p.p.m.
Onions	0–20–20 alone and with Cu or Zn.	37	18	19
Onions	0-20–20 and Mn. . . .	58	21	16
Potatoes	0–20–20 alone and with Cu, Zn, and S	8	—	5
Potatoes	0–20–20 and Mn.	14	–	6

READILY SOLUBLE MANGANESE IN SOILS

The fact that the plants on peat D gave no response to manganese and yet had a high concentration of manganese in their leaves led to a study of the amount of available manganese in this peat as compared to that of peats on which manganese was beneficial and also as compared to typical mineral soils.

Method of analysis.—The procedure adopted was as follows: Two grams of peat, dried at 100° C, were placed in a beaker and treated with 100 cc of 0.005 N H_2SO_4. With upland soils, 2 grams of air-dry soil were used. The soil was stirred well several times and allowed to stand overnight. The soil was then filtered off, the filtrate evaporated to dryness after the addition of 5 to 10 cc of nitric acid, and any organic matter remaining oxidized with several treatments of 10% hydrogen peroxide. The residue was taken up in the usual manner with nitric and sulfuric acids and the permanganate color developed with periodate.

Results.—Table 7 shows that peat B and the peat from the second greenhouse experiment were lower in manganese content than peat D. Both of the first two peats produced greater yields when fertilized with manganese, but peat D did not.

When considering Table 7, it is important to note that the weight of an acre-foot of mineral soil is often five times as great as that of peat soil; consequently, the peats studied have much less easily soluble manganese per acre-foot than the mineral soils, even though

TABLE 7.—*Readily soluble manganese in peats and mineral soils.*

Soil	Readily soluble manganese, p.p.m.	Soil	Readily soluble manganese, p.p.m.
Peat D	47	Colby silt loam	34
Peat B	26	Clinton silt loam	67
Peat from second greenhouse experiment	29	Dubuque silt loam	202
Plainfield sand	37	Miami silt loam	251
Sand from Hancock, Wis.	64	Superior clay	90
Boone fine sand	360	Quartz sand used in pot experiments	4
Vesper fine sandy loam	65		

some of the latter contain little more manganese in parts per million than the peats.

SUMMARY

Studies were made of the influences of boron on the growth and boron content of lettuce; of kaolin on the growth and manganese content of buckwheat in quartz sand cultures; of copper, manganese, and zinc on onions and sweet clover grown on peat in pot cultures; and of the influence of these elements on onions and potatoes grown on peat soils in the field. The plants grown on peat soils, as well as the soils themselves, were analyzed for manganese. The results obtained may be summarized as follows:

1. In quartz sand cultures, lettuce was unable to continue normal growth or produce a second growth of leaves unless boron was added. Plants showing the typical boron-deficiency symptoms produced new leaves and resumed normal growth after boron was supplied. Milorganite (activated sludge containing some boron) made possible nearly normal growth and increased the boron content of the lettuce. Boric acid prevented the appearance of all deficiency symptoms and doubled the boron content of the plants. Pyrex glass was also a good source of boron.

2. The application of kaolin to quartz sand cultures stimulated the growth of buckwheat and increased its content of manganese, but it inhibited seed production. Extraction of the sand and kaolin with dilute acid indicated that the manganese was obtained from the sand and not from the kaolin. The kaolin probably stimulated the feeding power of the buckwheat. The addition of manganese to the sand increased the yields appreciably.

3. Applications of copper and manganese to peat soils in pot cultures increased the growth of onions and sweet clover and the manganese content of the leaves. Some evidence was obtained that copper and manganese affected the relative growth of bulbs and tops and the maturation of the plants as well as the rate of growth.

4. Applications of copper, manganese, and zinc increased the yield of potatoes grown on peat soils in the field. The tubers of potatoes and the bulbs of onions grown on peat treated with copper appeared to be considerably better in quality than those not so treated.

5. Extraction of the soils with dilute acid showed that the peats studied had not more than one-third as much readily soluble manganese per acre as mineral soils. One peat, on which applications of manganese gave no increase in yield, contained more manganese than other peats from the same tract on which onions and potatoes responded to manganese. These results suggest that manganese-deficient soils may be identified by means of chemical soil analysis.

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A STUDY OF THE BASICITY OF DOLOMITE, ROCK PHOSPHATE, AND OTHER MATERIALS IN PREPARING NON-ACID-FORMING FERTILIZERS[1]

H. L. Cook and S. D. Conner[2]

It is well known that in humid climates soils tend to become more acid due to the leaching of bases. Certain fertilizers also make the soils more acid. The importance of this question has been emphasized in recent years as a result of the increasing amounts of fertilizers used and by the increasing physiological acidity of the fertilizers, which latter condition is largely due to the substitution of ammonium sulfate, ammonium phosphate, and liquid ammonia for organic nitrogen and sodium nitrate. This is borne out by the reports of Mehring and Peterson (21, 22).[3]

The purpose of the study reported here was to determine the basicity of dolomite, rock phosphate, and other materials in preparing non-acid-forming fertilizers.

REVIEW OF LITERATURE

In the last few years, developments in the fertilizer industry have resulted in the introduction of new phosphate carriers and also in the modification of the phosphate compounds present in a superphosphate as a result of ammoniation. Keenan (13) and Jacob and Ross (10) have shown that when ammonia is absorbed by superphosphate, di- and tricalcium phosphates are formed along with ammonium sulfate and monoammonium phosphate. The question has arisen as to the effectiveness of these phosphates in neutralizing the acid-forming property of the ammonium sulfate.

Although superphosphate has received considerable study, there has been little work conducted on the influence of mono-, di-, and tricalcium phosphates on soil acidity. Burgess (3) has shown that some of the work is apparently contradictory. In general, it has been found that superphosphate has no appreciable effect on acidity.

Conner (5) was one of the first to study this problem. His work is of special interest because it included studies with mono-, di-, and tricalcium phosphates. As measured by the Hopkins lime-requirement method (8), superphosphate was found to decrease the acidity of the soil when added in amounts of less than 4 to 8 tons per acre, but with greater amounts there were increases in acidity. Mono-, di-, and tricalcium phosphates were found to decrease the lime requirement of the acid soils used in the study. Conner (5) explained his results on the basis of the fixation of the soluble aluminum by the added phosphate.

It has been shown in recent years (7, 34) that phosphorous fixation in soils is considerably affected by soil reaction. It would seem to follow that the effect of

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[3]Figures in parenthesis refer to "Literature Cited", p. 854.

various phosphates on the soil acidity might vary with the original reaction of the soil. Pierre (24) has concluded that for most soils of the humid region, the pH value of which lies between 5 and 6, superphosphate, rock phosphate, and monocalcium phosphate can be considered as having no appreciable effect.

In recent years it has been suggested that dolomite or other basic materials should be added as the filler for fertilizers for correcting the physiological acidity.

Dolomite seems to be preferred to high calcium limestone. It has been shown by various investigators (4, 6, 12, 14) that the use of magnesium compounds, such as dolomitic limestone, has a beneficial effect on many soils. Recent investigations of MacIntire, *et al.* (15, 17, 19, 20) and of Ross (28) have shown that the use of high calcium limestone may result in losses of available phosphoric acid and ammonia under some conditions, yet such losses are negligible if dolomite is used.

The relation between degrees of fineness and the rate of decomposition of dolomitic limestone has been studied by MacIntire, *et al.* (16, 18), Morgan and Salter (23), Bear and Allen (2), and others. These investigators have established the general relationship between degrees of fineness and rate of reaction; and, also that dolomitic limestone reacts more slowly in the soil than does calcium limestone. Pierre (27) suggests for the preparation of non-acid fertilizers the use of limestone with a degree of fineness such that all will pass through a 40-mesh screen and at least 50% through a 100-mesh screen. Although coarser materials eventually become available in the soil, it is doubtful if they are sufficiently reactive to be considered effective in neutralizing the high acidity developed in the fertilizer zone during the first few months after application.

Recently, it has been suggested that rock phosphate might be used instead of dolomite in non-acid-forming fertilizer. Pierre (25), in an early publication, gave rock phosphate a high equivalent basicity. In a more recent paper (26), it was suggested that these values were high and a method of correction was proposed. This method of correction gives rock phosphate an equivalent value of about 200 pounds per ton of calcium carbonate. This is substantiated by the work of Smith, *et al.* (30), Pierre (24), and Ames and Richmond (1).

EXPERIMENTAL

The plan of this experiment was to study the effect of dolomite, rock phosphate, and other materials on the acidity developed by fertilizers when added to soils. Tests were made on two soils, one from Indiana, a Miami sandy loam subsoil with a pH of 4.8, and one from South Carolina, a Norfolk sandy loam, pH 5.4. Barley, rye, oats, wheat, and corn were grown successively on soils treated as shown in Table 1, and then to measure the cumulative effects, a final crop of barley was grown without further treatment. The crops were grown in Neubauer dishes with 800 grams of soil. The treated soils were fertilized with an 8-16-8 fertilizer at the rate of 1 ton per acre. This fertilizer was made up of 11-48 Ammo Phos, 20% superphosphate, 21% ammonium sulfate, and 63.3% potassium chloride. Magnesium sulfate was added to eliminate any magnesium effect of the dolomite. The fertilizer used had a calculated acidity of 844 pounds of calcium carbonate per ton and an equivalent acidity of 829 pounds of calcium carbonate, as determined by Pierre's method (26). This method consists essentially in titrating the excess of acidic or basic elements in the fertilizer after destruction of the organic matter by ignition. The neutralizing materials were added in amounts equivalent to this acidity. Thirteen treatments were set up and run in triplicate as shown in Table 1.

TABLE 1.—*Treatment of the soils.*

No.	Crop	Fertilizer per dish	Neutralizer
1	Crop	None	None
2	None	8–16–8*	None
3	Crop	8–16–8*	None
4	Crop	8–16–8*	0.33 gram 20- to 40-mesh dolomite
5	Crop	8–16–8*	0.33 gram fine (through 80-mesh) dolomite
6	Crop	8–16–8*	0.33 gram C. P. $CaCO_3$
7	Crop	8–16–8*	0.51 gram C. P. $Ca_3(PO_4)_2$
8	Crop	8–16–8*	0.77 gram 55.5% B.P.L. rock, equivalent to old Pierre value
9	Crop	8–16–8*	1.54 grams 55.5% B.P.L. rock, twice No. 8
10	Crop	8–16–8*	0.60 gram 74.2% B.P.L. rock, old Pierre value
11	Crop	8–18–8*	1.20 gram 74.2% B.P.L. rock, twice No. 10
12	Crop	8–16–8*	0.50 gram raw calcium silicate
13	Crop	8–16–8*	0.50 gram quenched calcium silicate

*0.8 gram in each case.

By using a procedure similar to that of the Neubauer test, it was thought that effects could be obtained more rapidly than by ordinary pot cultures. A thickly planted crop was grown, then removed, and the soil thoroughly leached to imitate the effect of rainfall which might occur during several months in the field. New fertilizer was added, another crop grown, removed, and the soil leached. After five such treatments, one crop was grown without additional fertilization to get the residual effect; then the soil was removed and mixed. Table 2 gives a brief outline of the procedure followed in the study. The following analyses were then made on soils from each treatment: the Jones acidity (11), Hopkins acidity (8), percentage saturation (29), and the pH in water and normal potassium chloride (31, 32, 33). Aliquots of the five leachings were taken, mixed, and analyzed for phosphorus, calcium, and magnesium.

TABLE 2.—*Order and time of experiments used in studies.**

Test No.	Date	Fertilizer	Incubation, days	Crop	Growth, days	Leaching
1	Febr. 23	1 ton	0	Barley	19	Yes
2	Mar. 20	1 ton	0	Rye	20	Yes
3	Apr. 17	1 ton + muck	13	Wheat	30	Yes
4	June 7	1 ton	10	Oats	15	Yes
5	July 16	1 ton	10	Pop corn	17	Yes
6	Aug. 5	None	10	Barley	35	No

*Soil analyses by Jones acidity, Hopkins acidity, percentage saturation, pH in H_2O, and N/KCl methods. Leachings and analyzed for P_2O_5, CaO, and MgO.

The results of the laboratory analyses of the two soils studied are shown in Tables 3 and 4 and expressed graphically in Figs. 3 and 4. Results of the analyses of the leachings are shown in Table 5.

DISCUSSION

The plants in Fig. 1 show the cumulative effect of the series of treatments upon the Norfolk sandy loam. Barley was used as it is very sensitive to soil differences. Treatments Nos. 6, 7, 12, and 13

proved to be better than the other treatments. Soils in Nos. 8, 9, 10, and 11, which were treated with the rock phosphate, showed very little beneficial effect. Probably due to nitrogen deficiency, as will be shown later, treatment No. 5 gave very poor plant growth. On the other hand, as shown in Fig. 2, where plants were grown on the Miami soil and where nitrification was not so rapid and nitrogen loss through leaching was less, treatment No. 5 showed the best growth. Similar to the data given in Fig. 1, Fig. 2 shows that treatments Nos. 6, 7, 12, and 13 gave better growth than Nos. 9, 10, and 11 which were treated with rock phosphate.

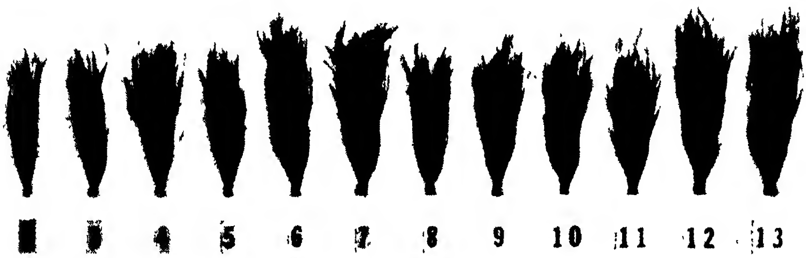

FIG. 1.—Barley plants on a Norfolk sandy loam.

FIG. 2.—Barley plants on a Miami sandy loam.

A study of Fig. 3, the numerical values of which are listed in Table 3, shows effects paralleling the growth results as shown in Fig. 1. Treatment No. 3 has been used as the base in evaluating these results. On the Norfolk soil where some nitrification occurred even in the most acid sets, addition of fertilizer in all cases increased the acidity. Although the coarse dolomite was of value, the fine-mesh dolomite gave the better results. The calcium carbonate used in treatment No. 6 was a C. P. product and was considerably more soluble and more easily leached out than the dolomite. Table 5 shows that there was considerably more CaO in the leaching of treatment No. 6 than in treatment No. 5, which probably accounts for the latter displaying the greater cumulative results. C. P. tricalcium phosphate had little if any advantage over the rock phosphate on the Norfolk

TABLE 3.—*Analysis of Norfolk sandy loam at end of tests.*

Treatment	pH water	pH KCl	Jones. lbs. $CaCO_3$	Hopkins. lbs. $CaCO_3$	Percentage saturation	NH_3	NO_3
1. Crop alone	5.43	4.70	1,120	40	65.3	–	–
2. Fertilizer alone	4.94	4.53	1,440	120	60.9	++	+
3. Crop+fertilizer	4.94	4.44	1,440	150	60.0	++	+
4. Crop+fertilizer, coarse dolomite	5.13	4.75	1,120	70	63.9	+	++
5. Crop+fertilizer, fine dolomite	5.65	5.21	960	20	66.7	–	++
6. Crop+fertilizer, C.P. $CaCO_3$	5.49	5.05	1,120	60	64.4	–	+++
7. Crop+fertilizer, C.P. $Ca_3(PO_4)_2$	5.02	4.76	1,280	130	60.1	+	++
8. Crop+fertilizer, low grade rock (single amount)	4.86	4.41	1,280	110	58.3	+	+
9. Crop+fertilizer, low grade rock (double amount)	4.86	4.34	1,380	120	55.7	+	+
10. Crop+fertilizer, high grade rock (single amount)	4.86	4.36	1,344	106	58.5	+	+
11. Crop+fertilizer, high grade rock (double amount)	4.76	4.34	1,410	136	55.9	+	+
12. Crop+fertilizer, raw $CaSiO_3$	5.82	5.48	960	16	72.3	–	+++
13. Crop+fertilizer, quenched $CaSiO_3$	6.18	5.88	800	16	83.0	–	+++

TABLE 4.—*Analysis of Miami sandy loam at end of tests.*

Treatment	pH water	pH KCl	Jones. lbs. $CaCO_3$	Hopkins. lbs. $CaCO_3$	Percentage saturation	NH_3	NO_3
1. Crop alone	4.93	4.02	2,720	1,000	54.4	–	–
2. Fertilizer alone	5.05	4.26	2,240	560	56.1	+	–
3. Crop+fertilizer	4.90	4.07	2,560	720	51.8	+	–
4. Crop+fertilizer, coarse dolomite	4.86	4.11	2,240	540	56.1	+	+
5. Crop+fertilizer, fine dolomite	5.36	4.27	2,080	460	57.6	–	++
6. Crop+fertilizer, C.P. $CaCO_3$	5.06	4.04	2,240	540	55.2	–	++
7. Crop+fertilizer, C.P. $Ca_3(PO_4)_2$	4.85	4.02	2,560	200	51.8	–	++
8. Crop+fertilizer, low grade rock (single amount)	4.97	3.99	2,560	600	52.9	+	–
9. Crop+fertilizer, low grade rock (double amount)	4.90	3.95	2,560	600	52.8	+	–
10. Crop+fertilizer, high grade rock (single amount)	4.95	3.98	2,560	660	51.6	+	–
11. Crop+fertilizer, high grade rock (double amount)	4.86	3.94	2,560	640	52.1	+	–
12. Crop+fertilizer, raw $CaSiO_3$	5.24	4.35	1,940	300	59.7	–	++
13. Crop+fertilizer, quenched $CaSiO_3$	5.34	4.60	1,940	270	60.5	–	++

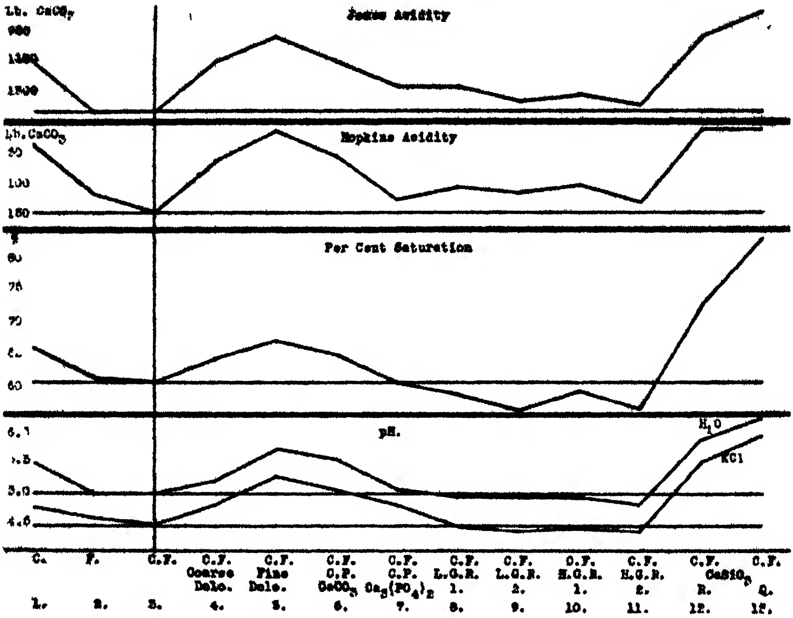

FIG. 3—Results of acidity determinations on Norfolk sandy loam.

Measured by Jones and Hopkins acidity, treatments Nos. 8, 9, 10, and 11 showed less acidity than the base determination (No. 3), but according to percentage saturation and pH, the acidity was greater. The double addition of the rock phosphate gave a more acid reaction than the single application. The increase in acidity noted by the percentage saturation and pH may possibly be due to some nitrification occurring on the treatments receiving the rock phosphate. The nitrifying process was probably stimulated by the slight basicity of the rock, but the acid so produced was in excess of the neutralizing effect of the latter. It was found that the calcium silicates gave good results; the quenched slag being slightly superior to raw slag. Attention is called to the good correlation between the various factors measured by five types of acidity determinations when applied to the same soil.

In the case of the Miami sandy loam, as shown in Fig. 4 and Table 4, the results are somewhat similar to those already discussed for the Norfolk sandy loam. Additions of fertilizer decreased the acidity slightly, as was noted by the Jones' and Hopkins' determinations. Since there was little nitrification observed, the decrease in acidity was probably due, as will be noted later, to a phosphate effect. The use of coarse dolomite, fine dolomite, and calcium carbonate gave similar results to those observed on the Norfolk sandy loam. The tricalcium phosphate had no effect except in the Hopkins determination in which case there was a noticeable reduction of the lime requirement, which probably can be attributed to the phosphate effect.

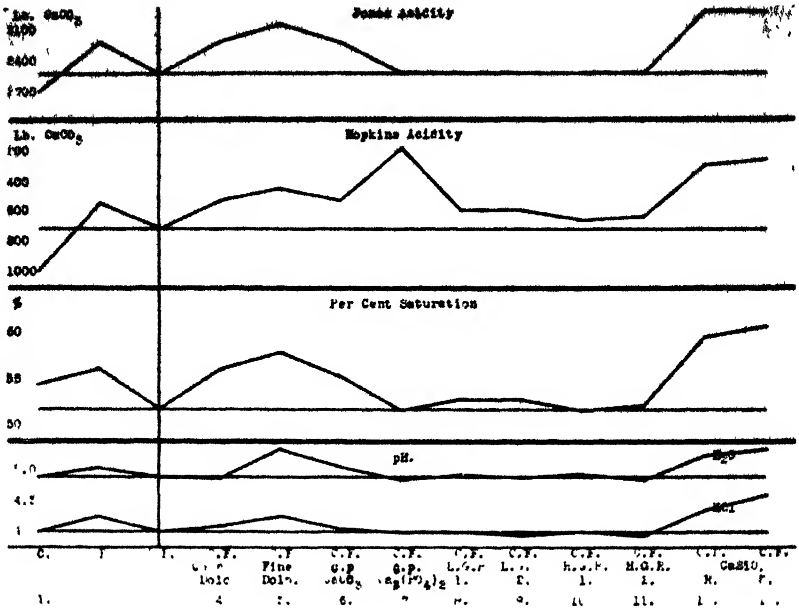

FIG. 4. Results of acidity determinations on Miami sandy loam.

The additions of rock phosphate had no effect, probably due to its insolubility. In contrast to the results already observed on the Norfolk soil, there was no increase in acidity since there was little, if any, nitrification in these cases. In the Norfolk series, the calcium silicates proved to be efficient. With the exception of the Hopkins determination on the soils of treatment No. 7, there was a close correlation between the different acidity values of the soils from each treatment. It is interesting to observe the similarity of the curves representing the same treatments on two very different soils.

These results show that under conditions such as prevailed in these experiments, fine dolomite or calcium silicate would give the best results when used in the preparation of non-acid fertilizers, and that rock phosphate would be of practically no value. These results conform with those of the field experiments reported from the Bedford, Indiana, experiment farm (9).

In order to explain the large decrease in acidity caused by the C. P. tricalcium phosphate on the Miami soil as measured by the Hopkins lime requirement, a series of experiments were conducted to determine the effect of phosphates on the Hopkins determination. The result of the trial with tricalcium phosphate on the Miami soil is shown in Fig. 5. A 2-ton application of tricalcium phosphate decreased the Hopkins lime requirement from 1,770 pounds of calcium carbonate per acre to 100 pounds; however, larger applications caused a slight increase, which was probably due to the fact that the tricalcium phosphate used had a slight lime requirement. It may be

of some significance, however, that in the series of treatments, No. 7 (Fig. 4), which received a total of 6,300 pounds of tricalcium phosphate per acre, had a lime requirement of 200 pounds per acre of calcium carbonate, while Fig. 5 shows a corresponding lime requirement of 200 pounds of calcium carbonate with the 3-ton application. As can be seen in Table 5 there was considerably more phosphate leached from the soil in treatment No. 7 than in any other treatment. This would indicate that the soil was saturated with phosphates and would explain the reduction of the Hopkins value.

TABLE 5.—*Analysis of soil leaching in parts per million.*

Treatment	P_2O_5		CaO		MgO	
	Miami	Norfolk	Miami	Norfolk	Miami	Norfolk
1. Crop alone.......	0.875	50.3	81.6	93.5	55.0	45.9
2. Fertilizer alone....	2.79	99.0	204.0	175.0	78.4	83.4
3. Crop+fertilizer...	4.29	98.0	158.0	169.0	71.3	83.4
4. Crop+fertilizer, coarse dolomite	4.5	92.7	199.0	239.0	79.5	100.0
5. Crop+fertilizer, fine dolomite...	4.29	90.4	233.0	274.0	101.3	158.0
6. Crop+fertilizer, C. P. $CaCO_3$....	5.21	86.4	367.0	368.0	73.4	87.5
7. Crop+fertilizer, C.P. $Ca_3(PO_4)_2$	21.3	139.0	263.0	292.0	71.6	87.5
8. Crop+fertilizer, low grade rock (single amount).	6.13	90.4	219.0	256.0	71.3	87.5
9. Crop+fertilizer, low grade rock (double amount)	6.71	106.9	210.0	268.0	73.4	87.5
10. Crop+fertilizer high grade rock (single amount)	5.42	98.0	210.0	262.0	73.4	87.5
11. Crop+fertilizer, high grade rock (double amount)	9.1	101.9	228.0	372.0	73.4	87.5
12. Crop+fertilizer, raw $CaSiO_3$.....	6.34	92.7	432.0	460.0	77.9	96.0
13. Crop+fertilizer, quenched $CaSiO_3$	—	82.8	—	435.0	—	91.7

The effect of monocalcium phosphate on the Hopkins method was determined on the Miami sandy loam. As shown in Fig. 6, applications up to 1.5 tons per acre decreased the lime requirement, while larger applications increased it. The pH was decreased slightly with increasing amounts. The next series of experiments was made to find the effect of 8–16–8 fertilizer on the Hopkins lime requirement. Fig. 7 shows that while the acidity, as measured by the pH was increased, the Hopkins lime requirement was decreased by applications up to 5 tons per acre.

Similar experiments were made on the Norfolk sandy loam instead of the Miami, and with the tricalcium phosphate and 8–16–8 fertilizer. As can be seen in Figs. 8 and 9, there was an increase in the Hopkins lime requirement with every application of material. With

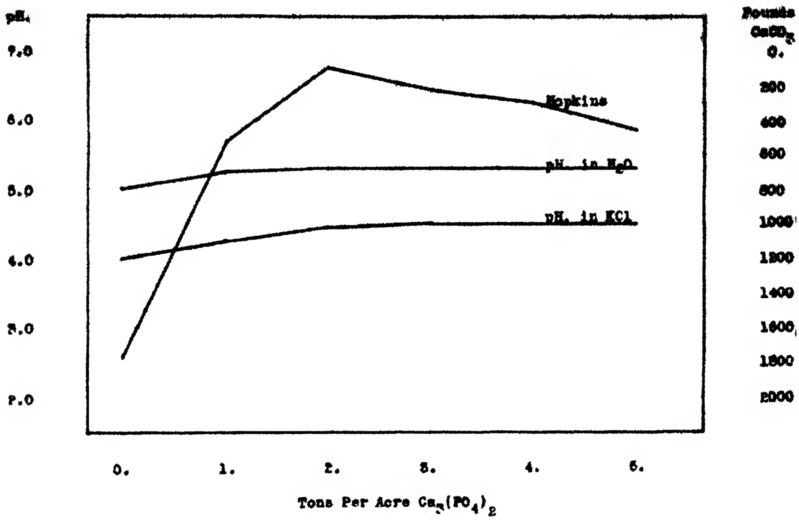

FIG. 5.—The effect of tricalcium phosphate on Hopkins acidity and pH when using Miami sandy loam.

the tricalcium phosphate, pH increased, while with the 8–16-8 fertilizer it decreased.

The results from the experiments on these two soils are explained on the basis that the Miami sandy loam has a considerable quantity

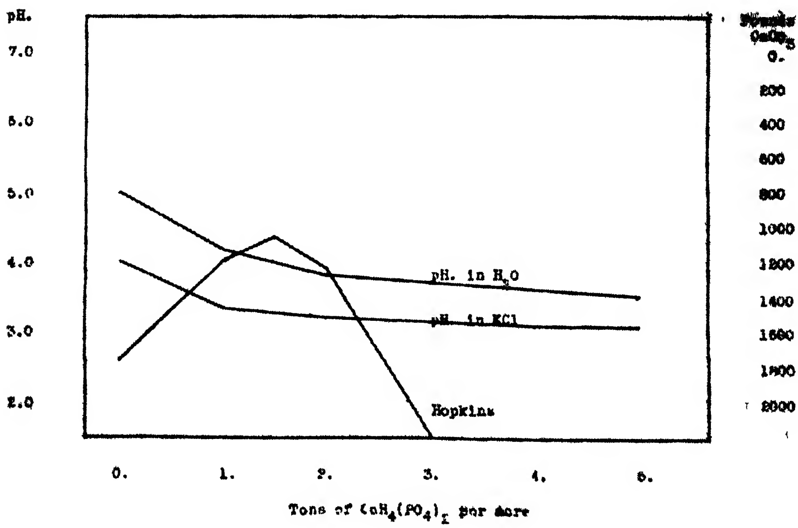

FIG. 6.—The effect of mono-calcium phosphate on Hopkins acidity and pH when using Miami sandy loam.

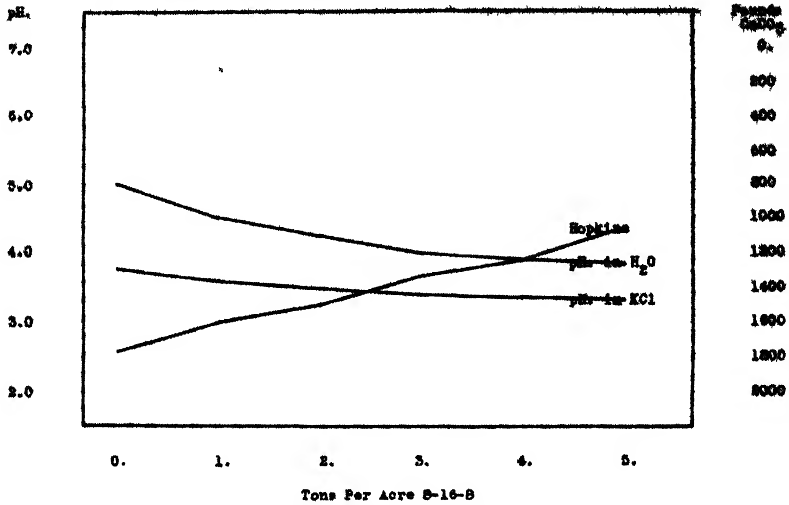

FIG. 7.—The effect of 8 16-8 fertilizer on Hopkins acidity and pH when using Miami sandy loam.

of exchangeable aluminum. The aluminum is fixed by the phosphate application, and, since the Hopkins determination is based on the exchangeable hydrogen and aluminum, it decreases until all the aluminum is fixed. In the case of the Norfolk soil, which has practically no soluble aluminum, the Hopkins lime requirement is not decreased by phosphate additions

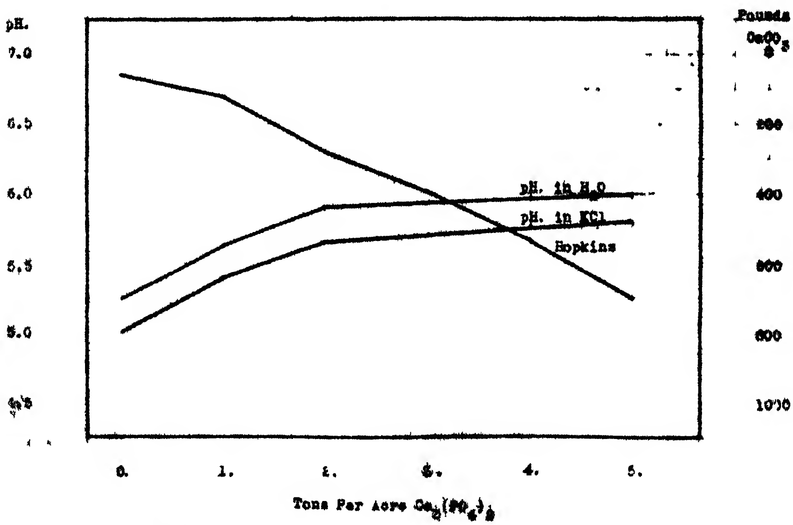

FIG. 8.—The results secured from using tri-calcium phosphate on a Norfolk sandy loam as measured by Hopkins acidity and pH.

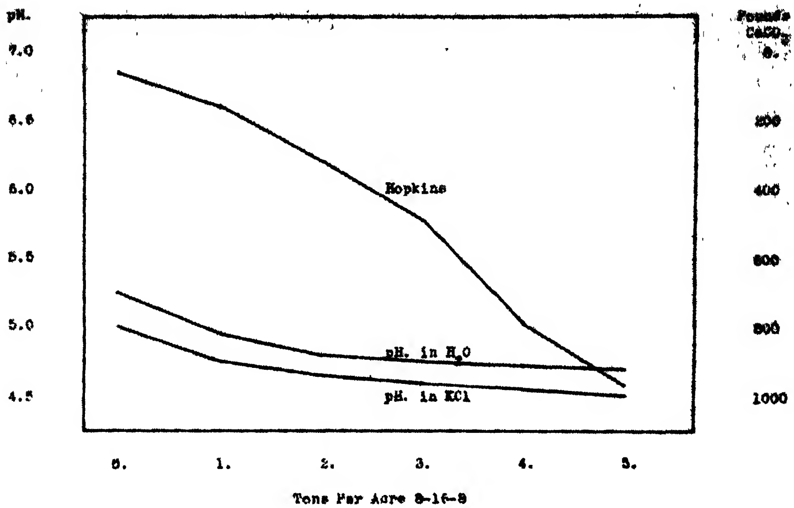

FIG. 9.—The results secured from using 8–16–8 fertilizer on a Norfolk sandy loam as measured by Hopkins acidity and pH.

SUMMARY

Results obtained with Norfolk sandy loam soil may be summarized as follows:

1. Additions of the fertilizer studied increased the acidity of the soil as determined by every method used.
2. Cropping the soil increased acidity.
3. Additions of dolomite, calcium carbonate, and calcium silicate reduced the acidity by every method used.
4. The coarse dolomite was not as good as the fine dolomite in reducing acidity.
5. The fine dolomite was the best of the carbonates in all cases.
6. The calcium carbonate was slightly better than the coarse dolomite but was not as good as the fine dolomite.
7. Tricalcium phosphate showed some value by the Hopkins and Jones acidity methods and by pH in KCl solution, but none by pH in water or by percentage saturation.
8. The four treatments with raw rock phosphate showed some neutralizing value with the Jones and Hopkins methods, but none by any other method.
9. The raw rock phosphate showed more acidity than the fertilizer alone by the pH and percentage saturation methods.
10. The calcium silicates were better than any other neutralizing material.
11. The quenched calcium silicate was slightly superior to the raw.
12. Attention is called to the similarity between the different methods when applied to the same soil.

Results obtained with Miami sandy loam soil may be summarized as follows:

1. Addition of fertilizer reduced acidity by the Jones and Hopkins methods.
2. Fertilizer increased acidity by the percentage saturation method but had no effect on pH.
3. Coarse dolomite reduced the acidity in all cases except pH, but was not as good as the fine dolomite.
4. Calcium carbonate reduced acidity in all cases except pH in water.
5. Calcium carbonate was not as good as fine dolomite.
6. Tricalcium phosphate showed no benefit by any method except Hopkins acidity.
7. Tricalcium phosphate showed an abnormally large reduction of the lime requirement by the Hopkins method on the Miami soil.
8. The raw rock phosphate shows a neutralizing value by the Hopkins method but not by any other method.
9. The calcium silicates were good neutralizers by all methods.

With the exception of the Hopkins acidity on the Miami sandy loam, there is a significant similarity in the trend of results between various treatments on both soils.

On the Norfolk sandy loam, the better nitrification may be the reason why the raw rock phosphate showed negative effects by pH and percentage saturation.

There was in all cases better nitrification with the fine dolomite, the calcium carbonate, the tricalcium phosphate, and the calcium silicates than with the fertilizer alone or fertilizer neutralized with raw phosphate.

In general, the pH curves of the two soils are similar. As can be seen in Table 5 the addition of dolomite increased the amount of both magnesium and calcium leached from the soil. The fine dolomite caused a greater loss than the coarse.

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THE INFLUENCE OF ORGANIC MATTER ON NITRATE ACCUMULATION AND THE BASE EXCHANGE CAPACITY OF DICKINSON FINE SANDY LOAM[1]

H. C. MILLAR, F. B. SMITH, AND P. E. BROWN[2]

A STUDY of the decomposition of humus-forming materials in the soil is of large practical as well as technical value. Many investigations (13, 10, 9, 2, 5, 3, 7, 4, 12, 1, 8)[3] have shown that a fairly close relationship exists between the rate of decomposition of organic matter in soils, the rate of carbon dioxide production, the accumulation of nitrates, and the numbers of bacteria. Comparisons of the rate of decomposition of some plant materials have been made but only for a small number of materials. The relation between nitrate accumulation in soils treated with plant materials and the nitrogen content of the materials added has been shown, therefore, only in a general way.

Base exchange studies on soils have shown that the organic matter fraction of a soil is responsible for a large part of its base exchange capacity. However, studies on the effect of specific plant materials on the base exchange capacity of soils are meager.

The purpose of the investigational work presented here was to determine the rate of decomposition of several humus-forming materials and to study the influence of these decomposing plant materials on the base exchange capacity of a Dickinson fine sandy loam.

METHODS OF PROCEDURE

The materials selected for the study were wheat straw, oat straw, sudan grass, cane sorghum, flax, cornstalks, millet, hemp, soybeans, alfalfa, sweet clover, and red clover. These crops were grown during the summer of 1934 and the tops (stems and leaves) of the plants only were taken for study. The crops were harvested, dried, and passed through a hammer mill. The materials were then brought to the laboratory and ground to pass a 40-mesh screen. Each sample was stored separately in large moisture-proof jars.

The effects of these materials on the nitrate accumulation in the soil, the exchange capacity of the soil, and the carbon and humus content of the soil were studied in three greenhouse and laboratory experiments.

The soil used in these experiments was a Dickinson fine sandy loam which had a pH of 6.33 and a lime requirement of 1 ton per acre.

EFFECT OF VARIOUS PLANT MATERIALS ON ACCUMULATION OF NITRATES IN SOIL

Twenty-six 1-gallon pots were filled with Dickinson fine sandy loam, and each of the plant materials was added to duplicate pots of

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[3]Figures in parenthesis refer to "Literature Cited", p. 865.

soil at the rate of 0.3%. Two pots were left untreated and served as checks. Calcium carbonate was added at the rate of 1½ times the lime requirement. The soil and organic materials were thoroughly mixed and the moisture content of the soil was adjusted to 25% and maintained at that amount throughout the experiment by additions of distilled water. The soils were sampled at intervals for determinations of the accumulation of nitrates. The soil samples taken at each date of sampling were mixed by the apparatus shown in Fig. 1.

The nitrate content of the soils at each sampling was determined by the phenoldisulfonic acid method and the results obtained are presented in Table 1.

The data in the table show that the plant materials containing the lowest amount of nitrogen had the greatest depressing effect upon nitrate accumulation in the soil. The average nitrate content of the soil was plotted against the percentage of nitrogen in the plant materials used and a highly significant correlation was found to exist (Fig. 2). This would seem to indicate that under a given set of conditions and within limits, the rate of decomposition of organic matter in the soil is determined by the amount of nitrogen present.

The time required to overcome the nitrate depression in the soils treated with 0.3% of the various plant materials was plotted against the percentage of nitrogen in the different materials. The results obtained are given in Fig. 3. The data show that the soils treated with plant materials poor in nitrogen required a proportionately longer time for the nitrate content to reach that of the check soil than for those treated with materials relatively rich in nitrogen. Plant materials having a nitrogen content less than 0.6% were found to decrease the nitrate content of the soils below that of the check soil for 3 months. Sweet clover with a nitrogen content of 3.1% depressed the nitrate content of the soil for only a few days.

INFLUENCE OF DECOMPOSING PLANT MATERIALS ON BASE EXCHANGE CAPACITY AND NITRATE ACCUMULATION IN SOIL

Twenty-six 4-gallon pots were filled with Dickinson fine sandy loam. Each plant material was added to duplicate pots of soil at the rate of 4%. Lime was added as calcium carbonate at the rate of 1½ times the requirement. The soil and organic materials were thoroughly mixed and the moisture content adjusted to 20% and maintained at that amount by frequent additions of distilled water. The experiment was started July 1 in the greenhouse and continued for 211 days. Samples were taken at intervals for determinations of the nitrate content and the base exchange capacity. The results obtained are presented in Tables 2 and 3 and Figs. 4 and 5.

The oat straw, wheat straw, sudan grass, cane sorghum, and hemp applied at the rate of 4% had a depressing effect on the nitrate content of the soil 7 months after treatment. These materials were all of relatively low nitrogen content. The nitrate content of the soil was averaged and the result plotted against the percentage of nitrogen in the plant materials used. A highly significant correlation was found to exist (Fig. 4). The soils treated with the leguminous materials

TABLE 1.—*The influence of a 0.3% treatment of plant materials on nitrate accumulation in soils.*

Soil treatment	N. %	Nitrate N in p.p.m.								
		Original, Mar. 1	Mar. 10	Mar. 30	Apr. 8	Apr. 15	Apr. 22	Apr. 29	May 27	June 17
Check	—	17.91	3.40	20.83	21.28	23.61	18.88	22.23	17.88	15.27
Oat straw	0.61	17.91	0.00	0.00	3.17	10.12	14.28	14.49	22.72	29.41
Wheat straw	0.50	17.91	0.00	0.00	0.00	5.90	6.20	6.68	15.38	22.23
Sudan grass	1.06	17.91	0.16	8.33	9.30	17.24	23.80	18.54	25.35	37.49
Cane sorghum	0.87	17.91	0.17	2.08	4.62	12.85	13.89	16.43	24.55	26.72
Flax	1.73	17.91	0.18	11.36	13.69	22.32	23.36	25.00	27.77	29.51
Cornstalks	1.20	17.91	0.00	0.00	4.26	10.12	12.82	18.52	27.86	32.25
Millet	1.17	17.91	0.00	0.00	5.38	18.69	15.27	15.15	17.85	38.69
Hemp	0.88	17.91	0.00	0.00	2.77	8.88	19.82	12.73	13.24	20.00
Soybeans	1.85	17.91	0.00	13.51	15.64	23.25	25.64	30.18	31.75	37.75
Alfalfa	3.07	17.91	0.21	37.03	40.83	43.55	40.06	47.73	57.57	54.03
Sweet clover	3.14	17.91	1.00	50.00	50.00	59.03	62.50	58.83	56.25	65.12
Red clover	2.20	17.91	0.25	13.69	13.88	23.25	22.22	28.59	40.07	41.66

FIG. 1.—Apparatus for mixing soil samples.

showed no depression of nitrates 1 month after treatment, but the soybean-treated soils showed a depressed nitrate content at the sampling 3 months after treatment. Flax and soybeans were similar in their effects on nitrate accumulation and also quite similar in total nitrogen content.

The base exchange capacity of the soils treated with the different plant materials was determined by the method outlined by Millar,

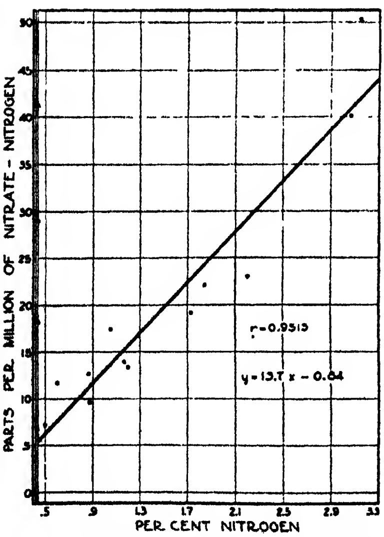

FIG. 2.—Relation between the nitrogen content of plant materials and nitrate accumulation in the soil (0.3%).

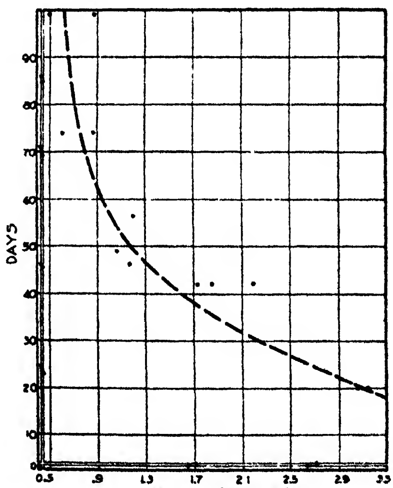

FIG. 3.—Relation between the nitrogen content of plant materials and the time required for the nitrate content of the treated soils to reach that of the untreated soils.

TABLE 2.—*The influence of 4% treatment of plant materials on nitrate accumulation in soils.*

Soil treatments	Plant materials		Nitrate N in p.p.m.					
	C, %	N, %	Original, July 11	Aug. 10	Sept. 9	Oct. 18	Nov. 18	Feb. 7
Check	—	—	28.16	53.34	82.20	65.58	83.91	75.40
Oat straw	39.00	0.61	28.16	0.00	0.00	0.00	0.00	0.00
Wheat straw	38.27	0.50	28.16	0.00	0.00	0.00	0.00	0.00
Sudan grass	40.30	1.06	28.16	0.00	15.09	50.50	72.47	68.96
Cane sorghum	39.11	0.87	28.16	0.00	0.00	7.80	36.17	68.71
Flax	39.70	1.73	28.16	21.73	58.87	55.55	121.47	187.50
Cornstalks	38.11	1.20	28.16	0.00	0.00	13.94	65.12	104.27
Millet	38.47	1.17	28.16	0.00	9.76	27.95	66.66	113.95
Hemp	38.92	0.88	28.16	0.00	0.00	9.84	10.00	26.28
Soybeans	36.41	1.85	28.16	57.14	47.61	65.38	153.40	154.70
Alfalfa	38.19	3.07	28.16	55.17	124.24	143.58	225.00	350.00
Sweet clover	38.35	3.14	28.16	55.30	190.47	104.27	162.38	366.66
Red clover	39.14	2.20	28.16	66.66	51.14	64.58	105.55	194.44

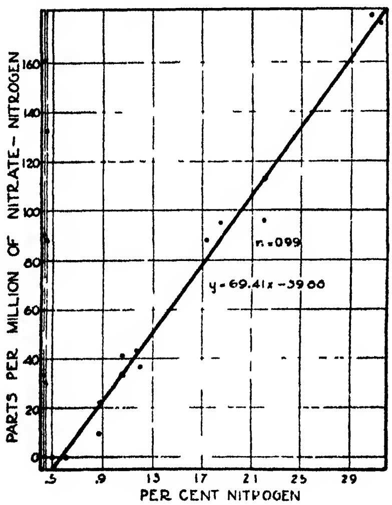

FIG. 4.—Relation between the nitrogen content of plant materials and nitrate accumulation in the soil (4.0%).

Smith, and Brown (6). The results obtained are given in Table 3 and Fig. 5.

The data show a wide variation in the base exchange capacity of the soil treated with the different materials. It may be observed that in the beginning of the experiment the exchange capacity of the soil treated with sudan grass was lower than that of the check soil. This is undoubtedly due to the fact that the exchange capacity of sudan grass was lower than that of the soil. The difference in the exchange capacity of the soils treated with the various plant materials remained about the same throughout the experiment. The exchange capacity of the soils treated with corn, millet, and flax apparently reached a maximum before the end of the experiment and the absorptive power of the soil decreased as a result of the decomposition of these constituents.

The exchange capacity of the soils increased as decomposition proceeded, but there was no consistent difference in the exchange capacity of the soils treated with the different plant materials as decomposition proceeded. The increase in the exchange capacity of the check soil was probably caused by liming.

TABLE 3.—*The influence of decomposing plant materials on the exchange capacity of Dickinson fine sandy loam.*

Soil treatment	M. E. Ba per 100 grams of soil		
	Original	After 60 days of decomposition	After 100 days of decomposition
Check	13.81 13.81	13.51 13.51	15.50 15.79
Oat straw	14.75 15.54	16.39 15.99	17.02 17.09
Wheat straw	14.78 14.38	16.92 15.63	16.26 17.78
Sudan grass	13.14 13.01	15.52 15.35	15.79 16.01
Cane sorghum	13.68 13.58	16.10 16.55	17.38 17.17
Flax	15.61 15.00	15.99 17.75	15.64 16.32
Cornstalks	14.38 14.34	17.66 16.90	16.30 16.95
Millet	14.41 15.01	17.60 18.06	16.80 16.59
Hemp	13.61 16.88	16.73 17.70	18.98 17.57
Soybeans	14.71 15.51	18.28 17.00	18.83 18.40
Alfalfa	14.74 15.41	16.55 17.61	18.61 17.48
Sweet clover	15.95 15.11	17.35 18.64	17.24 17.75
Red clover	16.25 16.21	17.44 16.33	17.67 17.75

SOME EFFECTS OF DECOMPOSING PLANT MATERIALS ON DICKINSON FINE SANDY LOAM

Five hundred grams of soil were placed in each of 26 600-cc beakers. Each plant material was added to duplicate beakers of soil at the rate of 5%. The soil and plant materials were thoroughly mixed. The moisture content of the soil was adjusted to 30% and maintained at that amount by additions of distilled water. After 289 days of decomposition at laboratory temperatures, the soils were air-dried, thoroughly mixed, and sampled for carbon, humus, and base exchange capacity. The carbon content was determined by the dry combustion method and the humus content by the method of Waksman (11). The base exchange capacity was determined by the barium

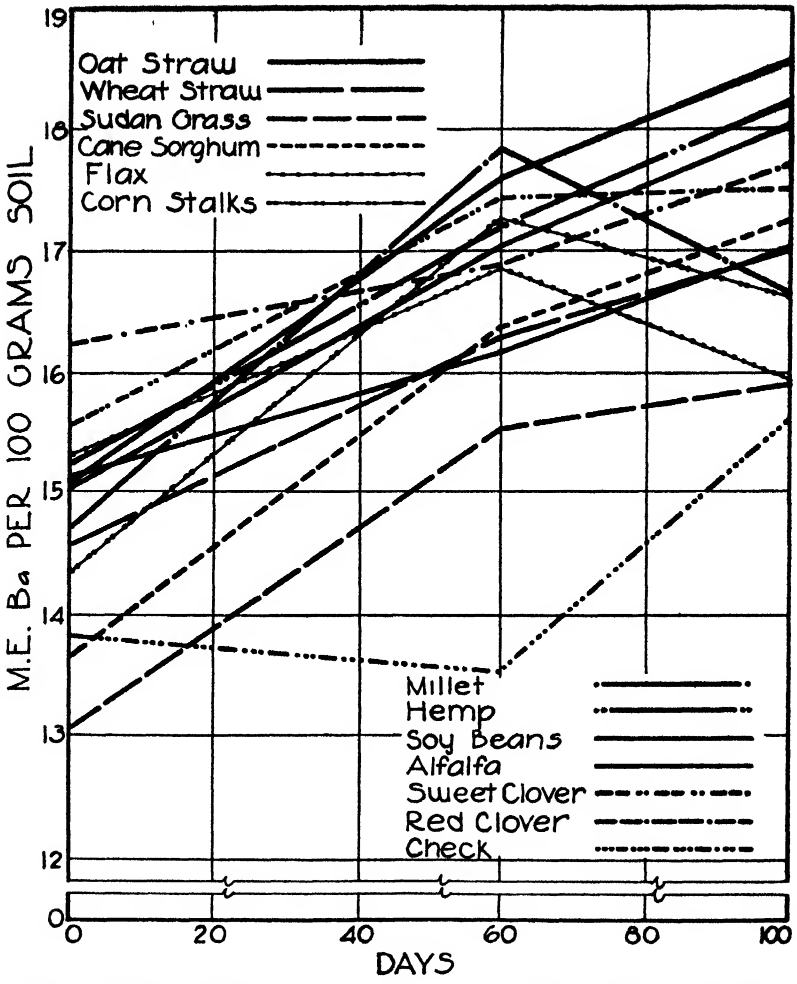

FIG. 5.—Base exchange capacity of soils treated with decomposing plant materials (4.0%).

acetate method (6). The results obtained are presented in Table 4 and Fig. 6.

The data show that in all of the soils treated with organic matter the base exchange capacity was increased above that of the check soil. There seemed to be little difference in the exchange capacity of the soils treated with cane, millet, sudan grass, hemp, cornstalks, and wheat straw. The exchange capacity of the soils treated with oat straw, red clover, flax, alfalfa, sweet clover, and soybeans was higher and more variable than in the first group of treatments named.

It is interesting to observe that the soils treated with plants high in nitrogen had a higher base exchange capacity than the soils treated

TABLE 4.—*Humus content and exchange capacity of soil treated with various plant materials.*

Soil treatment	Plant materials			M. E. Ba per 100 grams	Carbon content %	Humus a fraction %
	C, %	N, %	Ash-free lignin, %			
Check......	—	—	—	15.04	1.71	0.85
	—	—	—	15.04	1.71	0.97
Oat straw.....	39.00	0.61	15.98	16.86	2.41	1.52
	—	—	—	17.69	2.31	1.47
Wheat straw...	38.27	0.50	15.48	16.89	2.52	1.43
				17.10	2.56	1.45
Sudan grass ...	40.30	1.06	13.53	17.41	2.25	1.43
	—	—	—	16.36	2.21	1.43
Cane sorghum.	39.11	0.87	14.56	16.78	2.27	1.27
				16.78	2.23	1.37
Flax	39.70	1.73	15.17	17.60	2.17	1.14
	—	—	—	17.76	2.32	1.29
Cornstalks....	38.11	1.20	13.19	17.20	2.26	1.27
	—	—	—	16.75	2.25	1.21
Millet	38.47	1.17	11.81	16.71	2.40	1.14
	—	—	—	16.92	2.17	1.10
Hemp........	38.92	0.88	16.96	16.86	2.28	1.08
	—	—	—	16.92	2.16	1.09
Soybeans.	36.41	1.85	17.50	17.83	2.20	1.03
				18.39	2.18	1.03
Alfalfa	38.19	3.07	17.94	17.94	2.24	1.04
	—	—	—	17.94	2.21	1.04
Sweet clover...	38.35	3.14	14.39	18.11	2.23	1.16
	—	—	—	18.11	2.23	1.21
Red clover	39.14	2.20	14.40	17.48	2.32	1.22
	—	—	—	17.28	2.27	1.12

with plants having a low nitrogen content. The base exchange capacity of the treated soils was plotted against the nitrogen content of the plant materials added (Fig. 7). The base exchange capacity of this soil was increased when treated with organic matter and the increase in exchange capacity was significantly related to the nitrogen content of the organic matter added. The total carbon content of the variously treated soils was higher than that of the check soil, but the results showed no significant difference in the total carbon of the soils treated with the different materials. The a-humus content of the soils treated with the different materials was increased over that of the check soil, but the differences were not large and are not significantly correlated with any property of the original plant material studied.

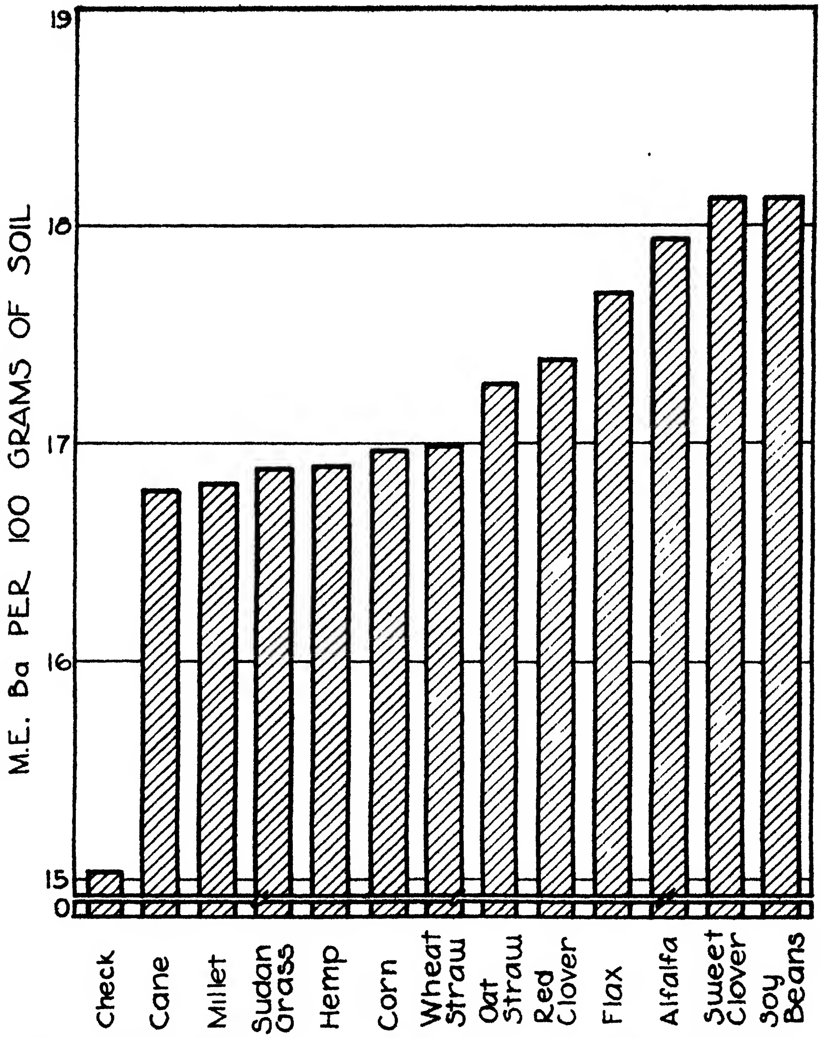

FIG. 6.—Base exchange capacity of soils treated with plant materials after 289 days decomposition (6.0%).

DISCUSSION AND SUMMARY

Experiments were conducted to study the effect of decomposing wheat straw, oat straw, sudan grass, cane sorghum, flax, cornstalks, millet, hemp, soybeans, sweet clover, red clover, and alfalfa on the accumulation of nitrates in the soil, the base exchange capacity of the soil, and the carbon and *humus* contents of the soil. The results obtained showed that the accumulation of nitrates in the soil was significantly correlated with the nitrogen content of the material added. The materials having a relatively wide carbon-nitrogen ratio

depressed nitrate accumulation in the soil to a greater extent than the materials having a relatively narrow carbon-nitrogen ratio.

The exchange capacity of Dickinson fine sandy loam was increased materially by the decomposing plant materials in one experiment and there was no consistent difference in the exchange capacity of the soils treated with the different plant materials as decomposition proceeded in another experiment. The first experiment was carried out under laboratory conditions and at about 25° C, whereas, the

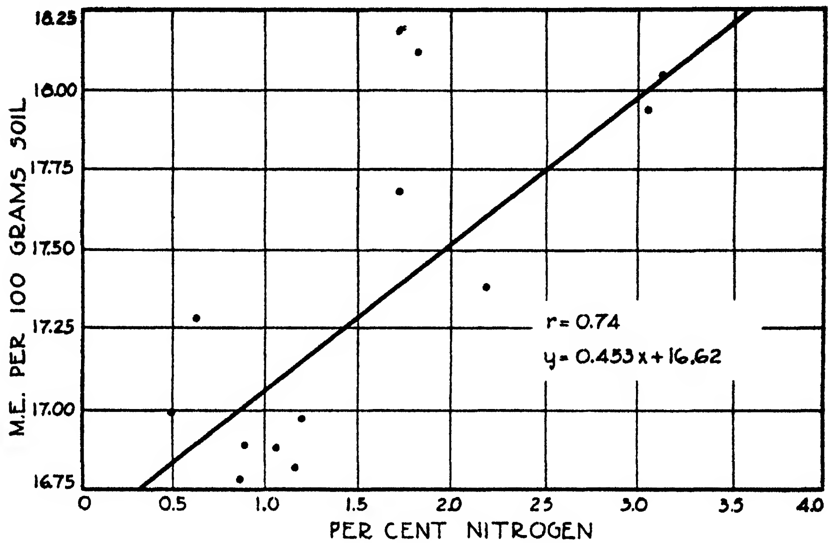

FIG. 7.— Relation between the base exchange capacity of the soils and the nitrogen content of the plant materials added.

second experiment was carried out under greenhouse conditions, beginning in July. The air temperature in the greenhouse was frequently above 110° F. The high temperature and the resultant increased decomposition of the materials undoubtedly explain the differences in the effect of the materials on the exchange capacity of the soil. In general, the leguminous materials increased the exchange capacity of the soil more than the non-leguminous materials.

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BOOK REVIEWS

ERGEBNISSE DER AGRIKULTURCHEMIE

By F. Alten and M. Trenel. Berlin: Verlag Chemie. Vol. 4 (1935), 229 pages, illus. 1936. RM 16 (special price to foreign countries RM 12).

A REVIEW of volume 3 of this work appeared in this JOURNAL (Vol. 27 : 1006. 1935). The 18 papers presented in this fourth volume were read before the Section of Agricultural Chemistry at the 49th meeting of the Verein Deutscher Chemiker held at Königsberg in July, 1935. The articles give an excellent review of the latest developments in agricultural chemistry.

The book is divided into five parts, namely, general, soil research, fertilizers, feeds, and nutrition. Some of the topics discussed include the determination of humus, mobility of phosphoric acid in the presence of humates, the estimation of soil nitrogen by determining its chlorophyll content, the chemistry of silage production, the carotin and vitamin C content of vegetables and other foodstuffs, etc.

Again it is apparent to what a great extent agriculture in general is indebted to chemistry. These volumes are written not only for research workers but also for the agriculturist and agronomist to keep them well informed on the latest results of research in agricultural chemistry in its practical relations. Because of the simple style and variety of topics discussed in the volume, this goal is well achieved. (Z. I. K.)

APPLICATION OF STATISTICAL METHODS TO AGRICULTURAL RESEARCH

By Harry H. Love. Shanghai: The Commercial Press, Ltd. VII+501 pages, illus. 1936. \$3. (G. E. Stechert & Co., New York City, American distributor.)

ALTHOUGH published in China, the text of this volume is in English, but the work is being translated into Chinese. The chapter headings are as follows: Introduction, Frequency Distributions, Graphic Illustration, Constants of Position, Constants of Deviation or Dispersion, Simple Correlation, Multiple and Partial Correlation, The Probable Error Concept, Curve Fitting, Goodness of Fit, Analysis of Small Samples and Application of Probability, Analysis of Variance, Analysis of Variance—Complex Experiment, Problems of Plat Technique.

The Appendix consists of the following tables: Sums of Powers of Natural Numbers; Values to Facilitate the Fitting of a Logarithmetic Curve of the General Formula $y=a+bx+c \log x$; Corresponding Values for r computed from r_r; Values for Facilitating Computation of the Probable Error of a Single Observation, and the Mean, from Bessel's Formula; Values for Facilitating Computation of the Probable Error of a Single Observation, and the Mean, from Peter's Formula; Estimating Probability Based on the Normal Probability

Integral Corresponding to values of $\frac{x}{\sigma}$; Odds for Various Values of $\frac{D}{P.E.}$; the Calculated Odds for the Z values of Student's Table for Estimating the Probability of the Significance of the Result; Odds Calculated from Student's t Table; Significance Values of r and R. A list of publications referred to in the text and an index complete the volume.

How often have younger workers asked for a simple, yet extensive, text that would not only show how the mathematics of statistics should be calculated, but especially how they can be applied to the data of experiments? There are several works in English, written previous to the recent developments in "small sample theory" and the method of variance, that could be recommended. Dr. Love in the present volume, however, not only covers this same ground, which might be termed "large sample biometry", but he also discusses in detail small sample statistics, the method of variance, and plat technic. The distinguishing feature of the book is the application of the various phases of all the methods, each one illustrated by one or more numerical examples worked out in every detail. The algebraic treatment has been reduced to a minimum and numerical application stressed. Furthermore, the author has maintained an excellent balance in handling the various phases of the subject.

The recent attention given to small sample mathematics (a very important subject) has caused some biologists to look upon this method as a labor-saving device and to misuse it (in the reviewer's opinion) by recommending that less data be taken even when the securing of a much larger sample is not only practical but very desirable. In homogeneous material a better understanding of the nature of the distribution involved may be obtained from a large sample than from a small one. Dr. Love has shown the value of both the small and large sample methods and has not stressed one to the detriment of the other. His treatment of the method of variance is excellent. For all these reasons the book can be highly recommended to the biologist who is beginning the study of biometry and whose training in mathematics may not be extensive. More advanced workers will find much of value also. The collection of tables in the appendix is a great convenience and forms a valuable addition to the text.

The book may also be recommended to those biologists who through inexperience, carelessness, or a glorified idea that biometrical analysis is paramount to all other considerations in research, do not take the proper precautions in designing experiments, are not careful in taking data, disregard important practical considerations, or draw erroneous conclusions from such analysis because of lack of consideration of all the factors involved. Either by direct discussion or by implication, attention is drawn to the fact that all these phases of an investigation are even more important than the mere calculation of statistical constants because, unless these various phases are considered, the constants may be wrong and erroneous conclusions may be drawn from the results obtained.

The book should be welcomed by students as well as by the more advanced biologists who use statistical methods as a working tool in their investigations. (F. Z. H.)

(N.B. Through an arrangement entered into by Dr. Love, the organizations that furnished the funds that made this book possible, and the publisher, all profits from the sale of the volume beyond the actual cost of production are to be devoted to fellowships in agriculture for Chinese students in China.)

AGRONOMIC AFFAIRS

STUDENT SECTION ESSAY CONTEST

ALL members of the society are urged to encourage undergraduate students to submit essays in the Student Essay Contest sponsored by the Society. The details and rules are given in the May JOURNAL, page 420. Essays must be in the hands of the Chairman on Student Sections, H. K. Wilson, Division of Agronomy and Plant Genetics, University Farm, St. Paul, Minnesota, not later than November 1, 1936.

NEWS ITEMS

DR. J. A. DEFRANCE has been appointed Associate Agronomist at the Rhode Island Experiment Station to fill the vacancy occassioned by the resignation of H. F. A. North. Dr. DeFrance, who was formerly associated with the Department of Horticulture at Cornell University and later with the Soil Conservation Service, will have charge of experiments in turf culture.

DR. HARALD E. HAMMAR, formerly with the Bureau of Standards in Washington, accepted a position as Assistant Chemist in the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, with headquarters at Shreveport, La., where he will direct fertility investigations on pecan orchards in Louisiana, Texas, and Arkansas.

VANCE GLOVER SPRAGUE, who received his doctorate in agronomy from the University of Wisconsin in June, 1935, has been appointed to the position of Assistant in Agronomy, College of Agriculture, University of Illinois. Dr. Sprague reported for work at Urbana June 29, 1936.

DR. IDE P. TROTTER, formerly Extension Agronomist at the University of Missouri, has been made head of the Department of Agronomy, Texas Agricultural and Mechanical College, College Station, Texas.

ERRATUM

IN THE article by Professor J. B. Harrington on "Varietal Resistance of Small Grains to Spring Frost Injury" published in the May, 1936, number of this JOURNAL (pages 374 to 388), attention has been called to the origin of the variety Marquis as given in Table 1 on page 376. This should read "Hard Red Calcutta ×Red Fife".

JOURNAL
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VOL. 28 NOVEMBER, 1936 NO. 11

EFFECT OF AGE UPON THE ABSORPTION OF MINERAL NUTRIENTS BY SUGAR CANE UNDER FIELD CONDITIONS[1]

ARTHUR AYRES[2]

THE mineral composition of sugar cane has been employed in Hawaii as an aid in determining the nutrient status of the soil. Conflicting views are held regarding the reliability of the method. It is the belief of the author that the method may lead to serious error unless the effects of other factors which influence the mineral composition of the cane plant are also known. It was the purpose of the phase of the investigation reported in Part I of this paper to determine the effect of one of these factors, namely age, upon the percentage composition of the cane plant.

Part II of this publication deals with an investigation of the changing demands which the growing cane crop makes upon the soil for mineral nutrients. Investigations by Stewart (11)[3] and by the author (1) have shown that the absorption of mineral nutrients is much more rapid at certain periods in the life of the cane plant than at others. Knowledge of these demands at successive stages of growth would enable the agriculturist more nearly to adapt his program of fertilization to meet the needs of the crop. Moreover, if fertilization were largely withheld during periods of negligible absorption, losses of added nutrients by leaching should be reduced. The matter is of particular importance locally in those regions which are subject to an annual rainfall of 100 and occasionally 200 inches.

EXPERIMENTAL

The experimental plat consisted of approximately 1,000 running feet of cane in rows 5 feet apart. The variety of cane grown in the experiment, H 109, is extensively planted in the Islands and from it is produced nearly half of Hawaii's annual output of sugar. In order to avoid as far as possible any effect upon the

[1]Contribution from the Department of Chemistry, Experiment Station of the Hawaiian Sugar Planters' Association, Honolulu, T. H. Received for publication March 23, 1936.

[2]Assistant Chemist. The writer wishes to express his appreciation to Dr. Francis E. Hance, under whose direction this investigation was conducted, and to associates for helpful advice and criticism.

[3]Figures in parentheses refer to "Literature Cited", p. 886.

rate of absorption of even temporarily localized concentrations of mineral nutrients, a soil was selected for the study which would require no fertilizer other than nitrogen to produce a normal crop of cane. The amounts of the principal nutrients present in the soil of the experimental plat as measured by extraction with 1% citric acid are shown in Table 1. The data, which are expressed in terms of pounds of nutrients per acre foot of soil, indicate supplies of these materials which are adequate for the production of a crop of sugar cane.[4]

TABLE 1.—*Pounds of available nutrients in surface acre foot of soil.*

Silicon	Calcium	Potassium	Phosphorus
4,600	13,000	775	2,750

Nitrogen in the form of ammonium sulfate was applied in amount corresponding to that which is generally used under similar field conditions by the plantations. A total of 200 pounds of nitrogen was applied as follows: Aug. 24, 1933, 50 lbs.; Sept. 1, 1933, 50 lbs.; Dec. 26, 1933, 50 lbs.; and Sept. 24, 1934, 50 lbs.

The experimental area was planted in August, 1931, and ratooned 2 years later in August, 1933, when the present investigation was begun. The plat was sampled at monthly intervals, beginning 1 month after the start of the ratoon and continuing until the age of 14 months had been reached. (Sugar cane is ordinarily harvested in Hawaii at ages ranging from 12 to 24 months.) Samples were selected in accordance with a carefully developed plan which was deemed well suited to the shape of the plat, the number of stalks to be removed per month, and the total number to be harvested in the course of the study. Not more than a single stalk was cut from a stool of cane. Outside rows which were necessarily subjected to more light and wind than inner rows did not contribute to the samples. Thirty stalks were selected at each harvest during the first 4 months and subsequently 20 stalks. Specimens were selected exclusively from the normal, vigorous members of the original stand of cane. Dry leaves appeared during the fourth month. Beginning with the fourth harvest, therefore, stalks to be cut at each succeeding period were tagged and stripped of adhering dry leaves. Hence, dry leaves present on the stalk at sampling one month later, plus those removed for safekeeping during the interim, represented the formation of this material during the preceding month. The crop passed through the first winter without flowering. Extensive flowering occurred the second winter and was already in evidence at the last period of harvest in October, 1934.

Immediately upon cutting, the plants[5] were removed to the laboratory where the dry leaves, green leaves, and stalks were separated. The plant material was then freed from extraneous matter by carefully cleaning with dampened cloths. In order that the distribution of nutrients in the stalk might be studied, that part of the plant was divided into sections as indicated below:

From tip of growing point 6 inches down stalk............. Section A
From base of Section A, 3 feet down stalk................. Section B
From base of Section B, 3 feet down stalk................. Section C

[4]Response to applications of potassium and phosphorus is seldom obtained in Hawaii when the quantities of these nutrients in the soil, as measured by 1% citric acid, are in excess of 625 pounds and 65 pounds, respectively, per acre foot.

[5]For lack of a proper name the word "plant" is frequently used in this paper to designate the aerial portion of the cane stalk plus the accompanying leaves.

From base of Section C, 3 feet down stalk ....Section D
From base of Section D, 3 feet down stalk ....Section E

This division was in part arbitrary and in part resulted from the findings of earlier investigations.

Since the plants were severed at the surface of the ground, there was usually a section of each stalk which did not find a place in the above classification. These pieces comprised an additional sample which, like the other samples, was weighed and subsequently analyzed. Determinations of the composition of the roots were not made. Dry weights of all plant materials harvested were obtained. Because the immediate stages in the preparation of the plant materials for analysis were time-consuming, samples were taken early in the day. Frequently at these times the cane was thoroughly wet as a result of early morning showers. This situation was further aggravated as a result of transpiration losses by the leaves during the period required to obtain the samples and in many instances rendered futile attempts to secure accurate green weights. Sampling was discontinued at the age of 14 months. This was made necessary by the lodged and tangled condition of the cane at this age and the consequent impracticability of obtaining further representative samples.

ANALYTICAL PROCEDURE

Determinations were made in duplicate upon the partially dried (1 to 5% moisture), comminuted material by the methods given below:

Calcium.—By removal of silicon, iron, aluminum, and phosphorus from the hydrochloric acid extract of the ash and volumetric determination of calcium as the oxalate.

Magnesium.—By the removal of silicon, iron, aluminum, phosphorus, and calcium from the acid extract of the ash and determination of magnesium by double precipitation of magnesium ammonium phosphate and subsequent ignition to magnesium pyrophosphate.

Nitrogen.- By the Gunning method for total nitrogen.

Phosphorus. – By separation with iron from the hydrochloric acid extract of the ash (following removal of silicon) and subsequent determination by the volumetric ammonium molybdate method.

Potassium.—By the removal of silicon, iron, aluminum, phosphorus, and calcium from the hydrochloric acid extract of the ash and the determination of potassium by the Lindo-Gladding method.

Silicon.—By the hydrofluoric acid method; occluded material remaining after destruction of the silicon being added to the filtrate from the silicon.

Moisture.—By drying to constant weight under vacuum at 80° C.

DISCUSSION

The problem of how best to present data may usually be solved by a consideration of the uses to which the data are to be put. Thus, where the percentage composition of the plant is being used as an indication of the supply of nutrients in the soil and where it is desired to show that this composition is not alone a function of the supply of soil nutrients, but of the age of the plant as well, it seems fitting to present the data upon the basis employed in such work, i.e., the percentage basis. Hence, in Part I of this discussion the results are

presented accordingly.[6] In Part II, on the other hand, where it is desired primarily to show the rates at which the several nutrients are taken up by the cane plant in the course of development, the data are expressed in terms of grams of nutrients per plant. For the purpose of illustrating the distribution of the absorbed nutrients between the dry leaves, green leaves, and stalk at successive ages, the data are also presented in terms of grams of nutrients per component part of the plant.

PART I

Changes with age[7] in the percentage composition of the green leaves.— In Fig. 1 is shown the percentage composition of the dry matter of

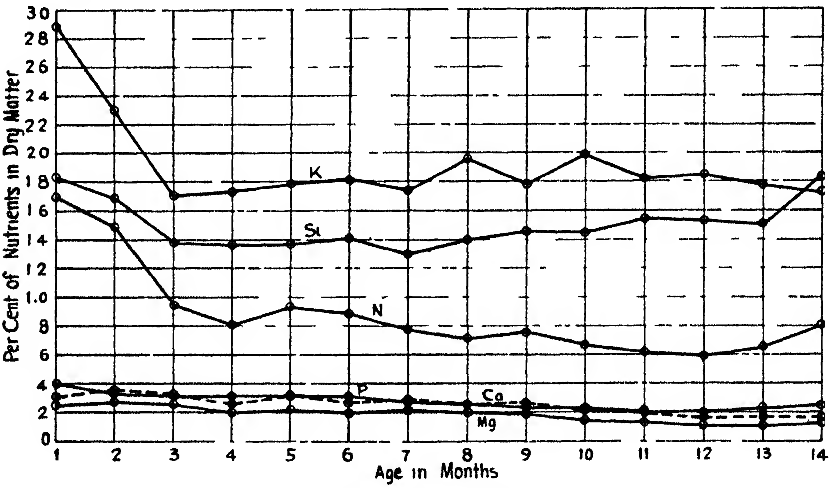

FIG. 1.—Changes with age in the percentage composition of the green leaves.

the green leaves at intervals of a single month, from 1 to 14 months. Referring to the figure, it will be observed that sharp decreases in the concentrations of potassium, silicon, nitrogen, and phosphorus occurred during the first 3 to 4 months of growth. Between this period and the age of 1 year changes were generally less marked. During the final 2 months of the experiment, the percentages of all nutrients in the leaves, except potassium, increased. These final changes appear to have been associated with the preparation of the plant to flower. Except in the case of silicon these findings are substantially those also of the earlier investigation of the plant crop (2). Hence, where the mineral composition of the leaves is to be taken as an indication of the nutrient status of the soil, it would appear advisable to confine sampling to periods during which the effect of age is least pronounced. This would exclude the sampling of the very young cane plant for such purposes.

[6]As has been noted, it was impractical to obtain green weights generally; hence the data showing the changes with age in the mineral composition of the plant are expressed upon the dry weight basis.

[7]It will be recognized that the effect of "age" actually includes the combined effects of age and season.

Changes with age in the percentage composition of the stalk.—The percentage composition of the dry matter of the stalk is shown in Fig. 2. Reference to the figure will show that except in the case of potassium the ratio of dry matter formed to nutrients absorbed (and remaining in the stalk) became constant at ages ranging from 8 to 12 months. It is not possible to conclude definitely from the data

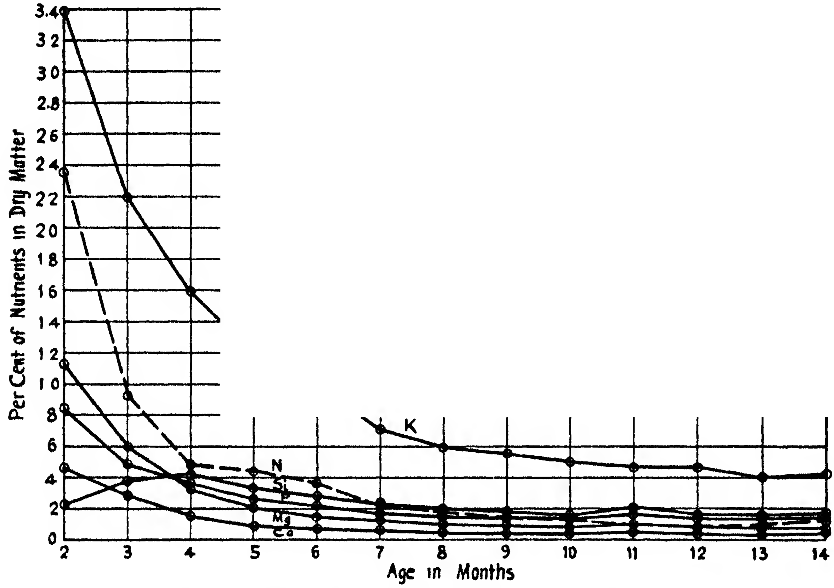

FIG 2.—Changes with age in the percentage composition of the stalk.

whether or not the concentration of potassium in the stalk had ceased to decrease even at the conclusion of the experiment at 14 months. In earlier related studies in Hawaii (1, 11), changes in the concentrations of nutrients in the stalk have been observed at ages considerably greater than those at which constant values were obtained in the present experiment. This difference possibly results from the fact that in the previous studies samples taken for analysis were so selected as to approximate the composition of the millable cane as a whole and hence contained stalks of various ages, whereas in the present investigation sampling was confined to the original stand of cane.

The foregoing considerations clearly illustrate the danger underlying the indiscriminate utilization of data pertaining to the mineral composition of the stalk of the cane plant, or of its juice,[8] as a guide to fertilization.

Translocation of nutrients in the leaves.—Recourse is again made to consideration of data upon the percentage basis in order to illustrate what appears to be a substantial movement of certain nutrients from the leaves back into the stalk. Thus, a comparison of the per-

[8]Honig (6) and Saint (10) have found a high degree of correlation between the mineral composition of the stalk and of the expressed juice.

centage compositions of the dry matter of green and dry leaves at each period of harvest shows the concentrations of nitrogen and of potassium to be very much higher, and that of phosphorus somewhat higher, in the former than in the latter. It might be argued that this does not prove translocation since the mass of green leaves at each harvest contained many young, succulent members which, on a dry weight basis, would be expected to contain larger proportions of these nutrients than the dry leaves. If this were the correct explanation, we should expect to find the dry matter of the green leaves richer also in such elements as calcium, magnesium, and silicon. The reverse, however, is the case.

In a recent investigation of the composition of the individual leaves of cane plants, the author found that generally the older the leaf the higher the concentrations (expressed on the dry weight basis) of silicon, calcium, and magnesium, whereas the reverse was true of nitrogen and potassium. From this observation also the suggestion is strong that large proportions of the nitrogen and potassium contained in the green leaves migrate back to the stalk before the leaves become physiologically inactive. Such migration in the cane plant in the instance of potassium has previously been observed by Boname (3), Hartt (5) and van Houwelingen (12). The latter obtained evidence also of the migration of nitrogen and phosphorus.

PART II

In the following discussion the demands made upon the soil for plant nutrients by the growing cane crop and the distribution of the absorbed nutrients within the several phases of the crop are considered. The quantities of nutrients and of dry matter contained in the green leaves, dry leaves, stalk, and entire plant, at successive ages, are shown in Table 2. The data are presented upon the basis of the number of grams of nutrients or of dry matter present in a single plant or part thereof. The data are also shown in more readily comprehensible forms in Figs. 3 to 9. Difficulties encountered in the selection of representative samples of the older cane were not appreciably present during the first part of the experiment and hence in the discussion which follows the greatest weight has been placed upon the results obtained during the earlier months.

Calcium.—Referring to Fig. 3, it will be seen that calcium was taken up by the cane plant at a rate which increased rapidly during the initial stages of growth and which attained a maximum value at the early age of 3 months. The rate of absorption reached at this point was generally maintained until the age of about 9 months when it commenced to diminish. The quantity of calcium contained in the green leaves increased until the age of 5 months when it became constant. A later decrease in the calcium content of the green leaves was coincident with the slight drop in the rate of absorption previously noted.

Magnesium.—Absorption of magnesium by the cane plant practically paralleled that of calcium at all stages of growth, as may be seen by a comparison of Figs. 3 and 4. A marked distinction appears,

TABLE 2.—*Grams of nutrients and of dry matter contained in the cane plant at ages of from 2 to 14 months.*

Age, months	Grams of Si	Ca	K	Mg	P	N	Dry matter
			Green Leaves				
2	0.26	0.054	0.35	0.039	0.050	0.23	15
3	0.51	0.12	0.63	0.093	0.11	0.35	38
4	0.84	0.16	1.06	0.12	0.19	0.50	62
5	1.14	0.27	1.49	0.18	0.26	0.77	84
6	1.49	0.28	1.93	0.21	0.33	0.94	107
7	1.34	0.29	1.79	0.21	0.28	0.80	104
8	1.56	0.28	2.21	0.21	0.29	0.81	112
9	1.84	0.33	2.26	0.23	0.29	0.95	127
10	1.99	0.28	2.75	0.19	0.30	0.93	138
11	1.73	0.21	2.05	0.15	0.24	0.70	113
12	1.77	0.19	2.16	0.12	0.22	0.68	117
13	1.74	0.18	1.98	0.12	0.25	0.73	112
14	2.47	0.22	2.32	0.17	0.33	1.09	135
			Dry Leaves				
4	0.29	0.050	0.042	0.030	0.020	0.025	8.8
5	0.43	0.079	0.079	0.048	0.033	0.040	15
6	0.57	0.10	0.12	0.066	0.050	0.060	22
7	0.95	0.18	0.25	0.11	0.098	0.11	40
8	1.00	0.30	0.53	0.20	0.17	0.18	73
9	2.04	0.38	0.70	0.26	0.21	0.22	93
10	2.46	0.45	0.83	0.30	0.23	0.26	110
11	3.22	0.56	1.09	0.36	0.28	0.32	142
12	3.81	0.64	1.32	0.40	0.30	0.36	167
13	4.33	0.70	1.43	0.43	0.33	0.40	188
14	4.79	0.75	1.56	0.46	0.35	0.43	208
			Stalk				
2	——	0.004	0.012	0.006	0.004	0.010	0.4
3	0.016	0.011	0.091	0.024	0.020	0.040	4.2
4	0.091	0.036	0.35	0.072	0.081	0.11	22
5	0.16	0.046	0.59	0.10	0.13	0.22	49
6	0.24	0.054	0.85	0.13	0.19	0.30	85
7	0.34	0.082	1.00	0.18	0.25	0.32	130
8	0.45	0.10	1.34	0.24	0.34	0.41	229
9	0.55	0.13	1.70	0.30	0.43	0.48	312
10	0.72	0.16	2.14	0.34	0.62	0.54	425
11	0.97	0.23	2.15	0.45	0.77	0.48	471
12	1.11	0.23	2.86	0.45	0.92	0.61	579
13	1.07	0.23	2.59	0.46	0.88	0.64	649
14	1.33	0.29	3.20	0.58	1.05	0.89	765
			Whole Plant*				
2	0.26	0.058	0.36	0.045	0.054	0.24	16
3	0.53	0.13	0.72	0.12	0.13	0.39	42
4	1.22	0.25	1.45	0.22	0.29	0.63	93
5	1.73	0.40	2.16	0.33	0.42	1.03	148
6	2.30	0.43	2.90	0.41	0.57	1.30	214
7	2.63	0.55	3.04	0.50	0.63	1.23	274
8	3.61	0.68	4.08	0.65	0.80	1.40	414
9	4.43	0.84	4.66	0.79	0.93	1.65	532
10	5.17	0.89	5.72	0.83	1.15	1.73	673
11	5.92	1.00	5.29	0.96	1.29	1.50	726
12	6.69	1.06	6.34	0.97	1.44	1.65	863
13	7.14	1.11	6.00	1.01	1.46	1.77	949
14	8.59	1.26	7.08	1.21	1.73	2.41	1108

*Green leaves, dry leaves, and stalk.

however, in the distribution of these two nutrients within the plant. Thus, at all stages of growth, much larger proportions of magnesium than of calcium were present in the stalk. Conversely, larger proportions of calcium than of magnesium were contained in the leaves.

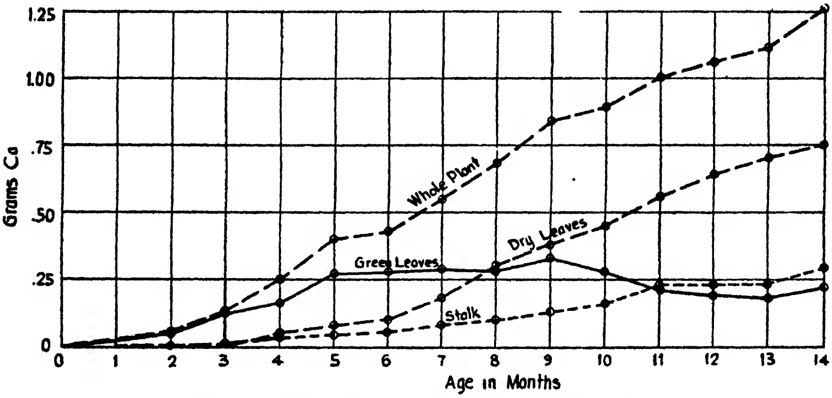

FIG. 3.—Absorption of calcium by sugar cane.

Phosphorus.—Reference to Fig. 5 will show that absorption of phosphorus was relatively slight during the initial 3 months of growth. Less than 10% of the quantity absorbed in the course of the first year was taken up during this period. Subsequently, phosphorus was absorbed by the cane plant at an increased rate which remained practically constant until the conclusion of the experiment.

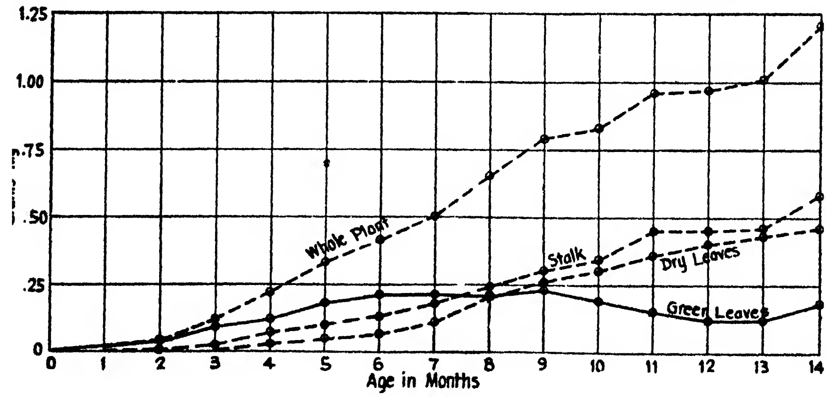

FIG. 4.—Absorption of magnesium by sugar cane.

This finding supports in part that of an earlier investigation (1) in which it was similarly found that phosphorus was taken up by the cane crop at a rate which was essentially constant after the initial 3 months of growth.

Phosphorus was found in the stalk to a greater extent than were any of the other nutrients studied. More than half of the absorbed

phosphorus was present in this organ of the plant after the age of 7 months.[9]

Silicon.—Reference to Fig. 6 shows that absorption of this constituent of the ash was very rapid following the first 3 months of growth, reaching a maximum rate at 7 months which remained

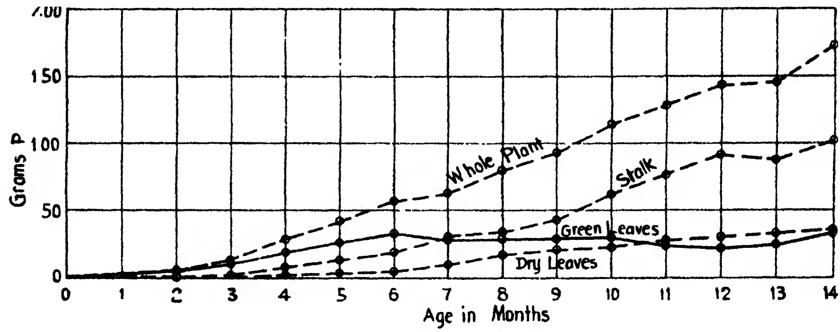

FIG. 5.—Absorption of phosphorus by sugar cane.

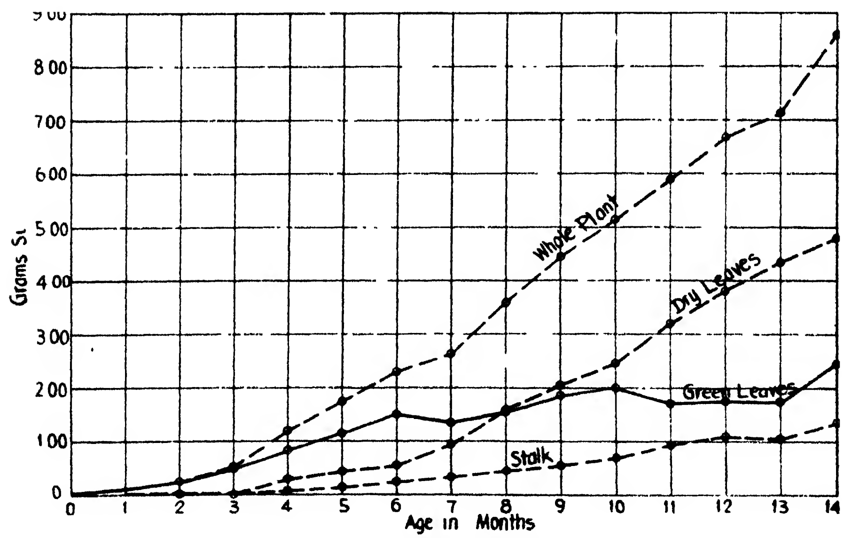

FIG. 6.—Absorption of silicon by sugar cane.

[9]The matter of the distribution of nutrients in the cane plant is of economical importance from the standpoint of the loss of nutrients from the soil. In Hawaii it is the practice to burn the fields prior to harvest. Preharvest burning destroys the dry leaves and to a degree the green leaves, depending upon the conditions under which the burn takes place. The fields are again burned after harvest with the result that the leaves not consumed in the first instance are reduced to an ash in the second. The minerals contained in the leaves and which are not lost as a result of the burning process are thus returned to the soil. Hence, with the exception of those which are largely lost through burning, e.g., nitrogen, it is the nutrients contained in the millable stalk which represent the permanent loss to the soil through cropping.

practically constant throughout the remainder of the experiment. In contrast to the cases previously considered, the silicon content of the green leaves did not reach a maximum until the age of 10 months. Only a small proportion of the silicon absorbed by the cane plant was found in the stalk at any period of harvest. At 14 months it amounted to but 15% of the total.

The rate at which silicon is taken up by the cane plant appears to depend largely upon the supply of the element available in the soil. Thus, while a 100-ton crop of sugar cane (plus accompanying tops and dry leaves, but exclusive of roots) grown on a certain Hawaiian soil (11) was found to have absorbed 475 pounds of the element, a crop of the same size, age, and variety but grown on a soil richer in soluble silicon (1) contained in the neighborhood of 800 pounds of silicon.

In culture studies Hartt (5) produced normal cane plants the silicon content of which was but a small fraction of that of the field-grown plants of the present experiment. Although Hawaiian soils are generally deficient in total silicon, an unusually large proportion of that present is in available form as has been shown by Maxwell (8). Comparing a large number of Hawaiian and continental United States soils, this investigator found that, "The soluble silicia in the Hawaiian soils is double the amount found in the American samples" and, he adds: "Agriculturally, this is probably of high importance, especially in the matter of the cane crop and of all cereal growths which incorporate large quantities of silica in their composition."

From the foregoing discussion and from the fact that the soil in which the cane of the present experiment was grown contained between 4,000 and 5,000 pounds of "available" silicon in the surface foot alone, it seems probable that the rate of absorption of the element here observed might well exceed that which would obtain in the case of sugar cane grown on soils less generously supplied with silicon. Unpublished data at hand indicate that the absorption of silicon by certain of the extensively planted Java canes would be still more rapid under the conditions of the experiment.

Potassium.—Referring to Fig. 7 it will be seen that the rate of absorption of potassium by the cane plant attained a maximum at the age of 3 months. During this period 11% of the first year's uptake of the nutrient occurred. The rate reached at this point was generally maintained until the age of 10 months when it commenced to diminish. It will be observed that this reduction in the absorption of potassium by the plant coincided with the acquirement by the green leaves of their maximum content of the nutrient. Thus, the reduced need of the leaves for potassium is reflected in a diminished absorption by the plant. Potassium was present in the stalks of the older canes to a relatively smaller degree than was phosphorus. Hence, loss of potassium from the soil through cropping would be proportionately less than in the case of phosphorus.

The findings of this investigation relative to absorption of potassium by the plant are generally in harmony with those of Stewart (11) who found that this nutrient was taken up very rapidly by sugar cane between the ages of 3 and 8 months but at a much slower rate during the remainder of the first year. In a later investigation (1)

potassium was found to be absorbed at a rapid rate between the ages of 3 and 12 months, but at a greatly reduced rate after 12 months. Work now in progress in this laboratory indicates that the demand made upon the soil for potassium by the variety of cane employed in this experiment (H 109) is greatly exceeded by that of certain other varieties.

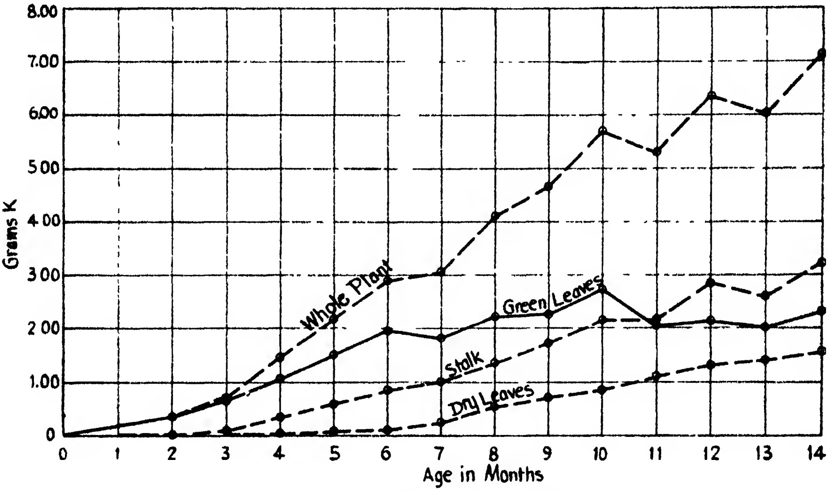

FIG. 7.—Absorption of potassium by sugar cane.

Referring to Fig. 9 in which is shown the growth of the cane plant as measured by the formation of dry matter, it will be observed that an era of rapid growth began at about the age of 7 months and continued until the end of the experiment. It might be expected that the commencement of this period of enhanced development would mark a corresponding increase in the uptake of potassium. Referring to Fig. 7, it will be seen that this was not the case. Moreover, while the absorption of potassium diminished after the tenth month, as has been pointed out, there was no corresponding diminution in the rate of growth of the cane plant. Hence, it appears that *the rate at which potassium is absorbed by sugar cane is not primarily a function of the rate of growth, but of the age, or of the stage of development, of the plant.*

Nitrogen.—Reference to Fig. 8 will show the results obtained for nitrogen to have been somewhat erratic during the second half of the experimental period. For this reason interpretation of the data can not be made as precise as is desirable. The rapid rate at which nitrogen was absorbed during the first 3 months of growth contrasts strikingly with the much slower uptake of the other nutrients studied. Nearly one-quarter of the nitrogen absorbed in the course of the entire first year was taken up during the initial 3 months of growth.[10] Absorption of nitrogen continued at a rapid rate until the age of 6 months was reached, when it generally diminished. A sharp

[10]It will be noted on page 872 that heavy applications of this nutrient were made at the start of the crop.

increase in the uptake of nitrogen at 13 to 14 months was coincident both with an application of ammonium sulfate to the experimental area and with the preparation of the plant to flower. Interpretation of this abrupt rise in the rate of absorption in the last month of the experiment is complicated by the possibility that both of these factors are involved. It appears probable, however, that the ammonium sulfate added at the age of 13 months was largely responsible for the

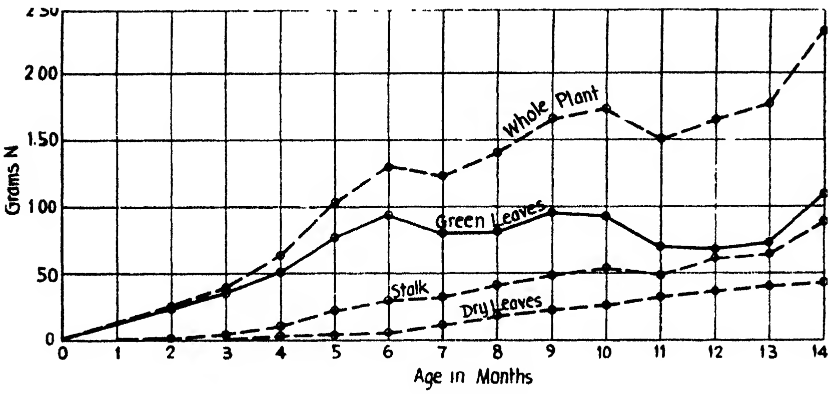

FIG. 8.—Absorption of nitrogen by sugar cane.

subsequently increased rate of absorption of nitrogen. Reference to Figs. 1 and 2 shows that the concentration of this element was greater following fertilization, both in the green leaves and in the stalk; yet there was no suggestion, either in the appearance of the crop or in the rate of growth (Fig. 9), that the plant lacked an adequate supply of nitrogen during the latter months of the study.

Das (4) has recently shown that absorption of nitrogen by sugar cane amply supplied with the nutrient may be yet further increased by additional applications of nitrogen. In the present instance, consideration must of course be given the possibility that increased growth, resulting from the fertilization, might have been noted had the experiment been extended for a period of several months.

It will be observed that the reduction in the rate of absorption of nitrogen noted at 6 months was coincident with the attainment by the leaves of their maximum amount of nitrogen. Thus, it appears that the requirement of the cane plant for this element decreases as soon as full development of the leaves has occurred. The parallel case of potassium has already been considered.

The lack of definite correlation between nutrient absorption and the growth of the plant as a whole is still more striking in the case of nitrogen than it is in the instance of potassium. Thus, for example, it will be seen by consulting Figs. 8 and 9 that the final increase in the rate of growth of the cane plant (7 to 8 months) was not accompanied by a corresponding increase in the uptake of nitrogen. On the contrary, the rate of absorption of nitrogen commenced to diminish just prior to this time. Hence, it appears that *the rate at*

which nitrogen is absorbed by sugar cane is, as in the case of potash, *not primarily a function of the rate of growth, but of the age or of the stage of development of the plant.*

Observations of Stewart (11) lend support to the findings of the present investigation. Referring to cane which has been grown to the age of 24 months, he says, "By the eighth month of the crop's growth. . . all the plots had taken up the largest part of the crop's

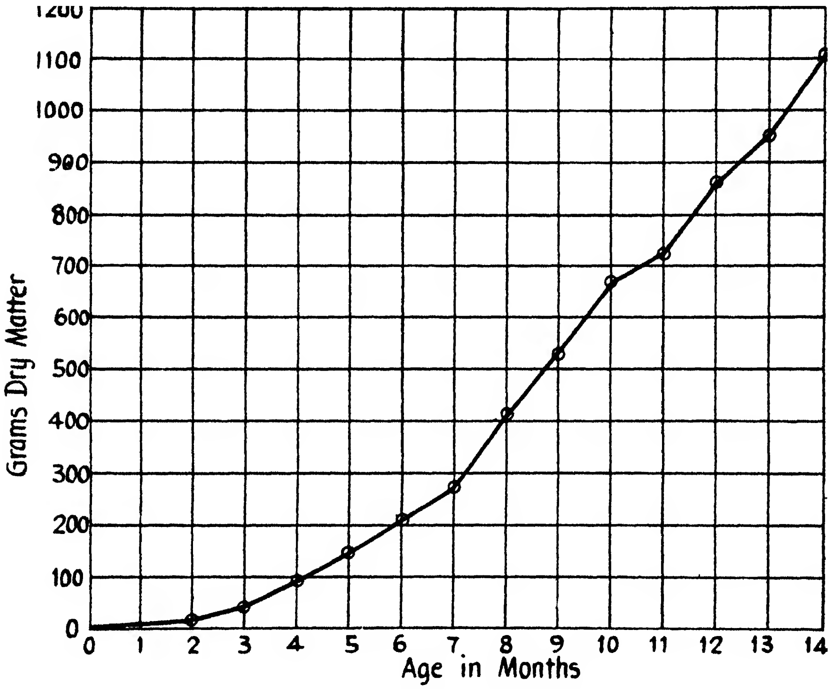

FIG. 9.—Growth of the cane plant.

total supply of nitrogen. There was a further gradual abstraction, but the more rapid absorption took place in the early months of the growth of the crop."

A more striking example of the ability of sugar cane to grow normally after the attainment of a certain stage of development with little or no further absorption of nitrogen is provided in a subsequent study by Stewart and the author (1). In this investigation 323 pounds of nitrogen per acre were applied to the crop during the initial 6 months of growth and none thereafter. Portions of the crop were harvested at intervals of 3 months up to the age of 2 years. From this experiment the surprising result was obtained that the crop at 24 months contained no more nitrogen than at 12 months; yet the yield per acre of millable cane increased during that period from 50 to nearly 100 tons.

That the early absorption of the bulk of its nitrogen by sugar cane is not peculiar to this plant is clearly seen by reference to the work of Russell (9) who finds that, "Most of the nitrogen required by the plant is absorbed in its early days from the soil and is stored in the meristematic tissues. . ."

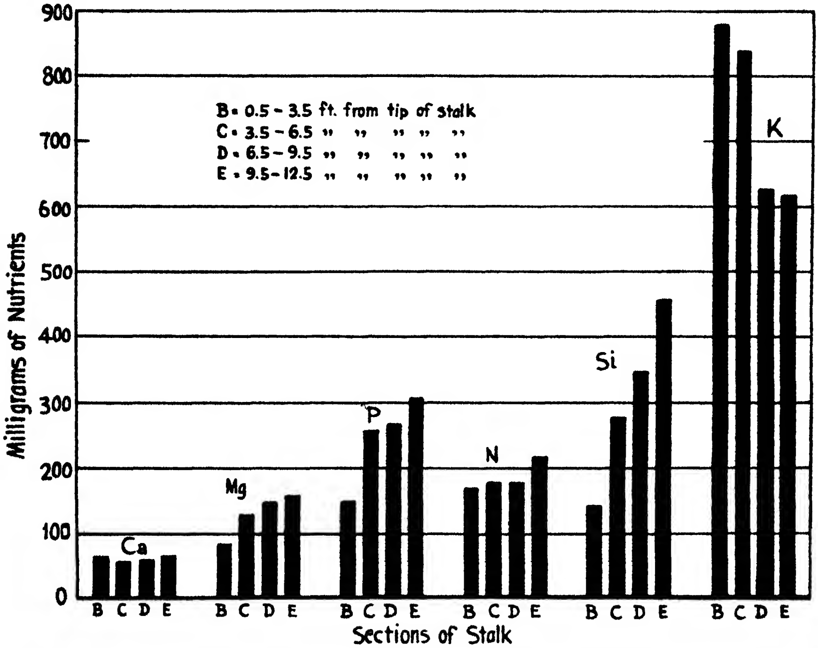

FIG. 10.—Distribution of nutrients in the stalk of sugar cane at 14 months.

Rapid early absorption of nitrogen, as compared with certain other nutrients, has also been observed by Knowles, Watkin, and Hendry (7) in the case of the sugar beet. These investigators state that, "A striking contrast in the period of the plant's history at which assimilation of nutrients is proceeding rapidly is shown in the case of phosphoric acid and nitrogen. Thus, at 7 weeks after singling, the plant contained less than one-half of its maximum quantity of phosphoric acid, but four-fifths of its maximum quantity of nitrogen. Assuming that this is normal, it is obvious that the plant is very dependent on supplies of available nitrogen in its earlier stages." If it is likewise assumed that the rate at which nitrogen was absorbed by the cane plant in the present investigation is normal, or even approximates the normal, then it must be concluded that sugar cane, like the sugar beet, is "very dependent on supplies of available nitrogen in its earlier stages."

Translocation of nutrients in the stalk.—The quantities of the several nutrients contained in successive 3-foot sections of the stalk of the cane plant at 14 months are shown in Fig. 10. Reference to the figure will show that as the base of the stalk is approached the

quantities of mineral nutrients per unit length thereof, with the exception of potassium, tend to increase, in several instances very markedly. Potassium, on the other hand, is seen to decrease in this direction. It thus appears that as the younger tissues of the stalk mature they lose potassium through the upward migration of the nutrient. This movement of potassium in the stalk of the cane plant has been previously observed by Boname (3), by the author (2), and by others.

SUMMARY

A study has been made of changes which occur with age in the mineral composition of the sugar cane plant.

It was found that the percentage compositions (mineral) of the leaves and of the stalk of the cane plant are markedly influenced by the age of the plant, particularly during the early months of growth. Hence, danger underlies the indiscriminate utilization of data pertaining to the percentage composition of the cane plant as an indication of the nutrient status of the soil.

The dry matter of dead cane leaves was found to contain much lower concentrations of potassium and nitrogen than that of green leaves. This is accounted for on the basis that these nutrients migrate from the leaves back to the stalk before the leaves become physiologically inactive.

The cane plant was found to absorb the necessary mineral nutrients in widely differing amounts. Potassium and silicon were taken up to the greatest extent, while nitrogen and phosphorus were absorbed in relatively moderate quantities. Of the nutrients studied calcium and magnesium were absorbed in least amount.

The rates at which the several mineral nutrients were absorbed were found to vary with the age of the plant, but not always in the same degree. The rates of absorption of all the elements studied, excepting silicon, reached maximum values by the early age of 3 months. During this period approximately 10% of the first year's uptake of phosphorus and potassium occurred. The corresponding quantity of nitrogen was much greater, amounting to nearly 25%. After the age of 6 months in the case of nitrogen and after about 10 months in the case of calcium, magnesium, and potassium, the rates of absorption diminished. Uptake of silicon and phosphorus, on the other hand, continued at essentially constant rates until the conclusion of the experiment at 14 months.

The rates of absorption of potassium and nitrogen were found to decrease immediately following the acquirement of maximum quantities of these nutrients by the leaves.

From the results of this study it appears that the absorption of nitrogen and potassium, and probably other nutrients, by sugar cane is not primarily a function of the rate of growth, but of the age, or of the stage of development, of the plant.

Pronounced differences were found in the distribution of the elements between the components of the crop. These differences were most marked in the instances of phosphorus and silicon. The quantities of these nutrients in the stalk (at the final harvest) amounted to 60 and 15%, respectively, of the totals taken up by the plant.

Evidence is adduced which indicates gross luxury consumption of silicon by Hawaiian-grown canes.

Examination of the distribution of potassium in the stalk suggests that as the meristematic tissues mature they lose potassium by upward migration of the nutrient.

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STUDIES ON THE REFRACTIVE INDICES OF EXPRESSED JUICE IN WHEAT SEEDLINGS[1]

KOICHI EBIKO[2]

MANY investigations have already been reported on the physico-chemical properties of wheat seedlings. The studies described in this paper were made with the purpose of finding the refractive indices of expressed juice as one of the physico-chemical characters of wheat seedlings.

RELATION BETWEEN REFRACTIVE INDEX AND SPRING AND WINTER GROWING HABIT

MATERIALS AND METHODS

The data used in this study were obtained on eight varieties of the winter wheat and six varieties of spring wheat as follows:

Winter Type	Spring Type
Ro No. 49	Rouge prolifique barbe
Kanred	Haynes
Akasabishirazu No. 1	Ro No. 30
Moscow 4	Meisaku
Trappist	Wasekomugi
Ohio	Manchuria No. 142
Ro No. 56	
Ro No. 57	

Since the plant juice must be greatly affected by environmental factors, it would seem that trustworthy results could not be obtained if the plants were grown under natural conditions. Hence, in these experiments, temperature, which seemed to be one of the most important environmental factors, was controlled, with cultures grown at high (20° to 32°C), moderate (5° to 10°C); and low (0° to 5°C) temperatures.

Sand cultures, using common river sand, were used to insure as nearly complete uniformity as possible.

Twenty plants of each variety were grown in 3.5-inch petri dishes filled with river sand without fertilizers. At the same time, 15 seeds of each variety were also planted in 3.5-inch clay pots filled with loamy clay soil, as controls. In both cases, care was taken to insure as nearly constant cultivating conditions as it was possible to obtain.

The refractive indices of the expressed juice were determined with the Goerz refractometer by means of which both refractive indices and total solids can be determined at the same time, despite the fact that the reading scale on this instrument is not altogether satisfactory.

The tests were made on seedlings which had reached approximately the same stage of development. The entire plant, except the roots, was cut into pieces of

[1]Contribution from the Division of Agronomy, Department of Agriculture, Saghalien Central Experiment Station, Karafuto, Japan. Published with the approval of the Director. Received for publication May 14, 1936.

[2]Agronomist. The author wishes to express his sincere appreciation to Professor M. Akemine, College of Agriculture, Hokkaido Imperial University, for his kind guidance throughout the present study. The writer is also greatly indebted to Y. Watanabe of this station for his hearty cooperation in this experiment.

1 to 2mm with shears and was ground thoroughly in an agate mortar with a pestle. The expressed juice was then obtained from these broken tissues by wrapping them in filter paper and expressing by hand as soon as possible.

The refractive indices given in this paper are the average value of two or three measurements for each variety. In each measurement three or four seedlings were generally used.

EXPERIMENTAL RESULTS

High temperature culture.—As it is difficult to obtain a high temperature during the winter period in Saghalien, the northern island in Japan, the high temperature culture was made by placing the plants in a large incubator. Seeds were sown in pots on March 1 and in petri dishes on March 24, 1933. After sowing, they were transferred directly to an incubator, closing the glass doors only. By this method the temperatures were controlled from 32° to 22° C in the petri dishes and from 30° to 20° C in the pots. However, as the seedlings tended to elongate somewhat too much in the incubator owing to insufficient light intensity, the plants of the pot culture were transferred into a room with temperatures of 16° to 10° C for about 8 hours in the middle of the day, where the seedlings were exposed to direct light passing through window glass in order to prevent excessive elongation. The summarized data are presented in Table 1.

TABLE 1.—*Relation between refractive indices and total solids in juice and the spring and winter growing habit in high temperature cultures.**

Variety	Sand culture			Pot culture		
	Average height of plants, cm	Refractive indices	Total solids,† %	Average height of plants, cm	Refractive indices	Total solids,† %
Winter Growing Habit						
Ro No. 49	13.3	1.3470	9.4	13.0	1.3476	9.8
Kanred	12.2	1.3470	9.4	—	—	—
Akasabishirazu No. 1	13.8	1.3454	8.3	—	—	—
Moscow 4	12.6	1.3457	8.5	11.4	1.3474	9.7
Trappist	13.0	1.3451	8.1	15.0	1.3470	9.4
Ohio	14.4	1.3457	8.5	16.9	1.3473	9.6
Ro No. 56	12.3	1.3454	8.3	14.4	1.3482	10.2
Ro No. 57	—	—	—	11.3	1.3479	10.0
Average	13.1	1.3459	8.6	13.7	1.3476	9.8
Spring Growing Habit						
Rouge prolifique barbe	14.5	1.3449	8.0	13.9	1.3455	8.4
Haynes	12.6	1.3448	7.9	12.6	1.3461	8.8
Ro No. 30	12.9	1.3457	8.5	13.4	1.3449	8.0
Meisaku	13.3	1.3454	8.3	14.6	1.3461	8.8
Wasekomugi	13.0	1.3440	7.4	14.0	1.3443	7.6
Manchuria No. 142	14.8	1.3452	8.2	12.7	1.3460	8.7
Average	13.5	1.3450	8.1	13.5	1.3455	8.4

*Temperature at reading 20°C.
†Total solids in juice were measured at the same time as refractive indices.

There were no considerable differences between the refractive indices of the winter and spring varieties in the sand cultures, although the juice of the former tended to show somewhat greater refractive indices than that of the latter. In the pot cultures, on the other hand, the refractive indices of the juice were distinctly greater in the winter varieties than in the spring varieties, on an average. These differences were probably largely due to the low temperature conditions brought about as a result of transferring the plants every day to the room at 16° to 10° C. For this reason, it is better to attach more weight to the results obtained with the sand cultures in this experiment.

Moderate temperature culture.—Seeds were sown in pots on March 1 and in petri dishes on March 8, 1933. They were germinated and grown in an incubator until about 7 to 10 cm in height when they were taken to a room maintained at a temperature between 10° and 5° C. After 7 days in this room, the refractive indices and total solids of the expressed juices were determined.

The results obtained are shown in Table 2.

TABLE 2.—*Relation between refractive indices and total solids in juice and the spring and winter growing habit in moderate temperature cultures.**

Variety	Sand culture			Pot culture		
	Average height of plants, cm	Refractive indices	Total solids, %	Average height of plants, cm	Refractive indices	Total solids, %
			Winter Growing Habit			
Ro No. 49	12.6	1.3534	13.5	12.5	1.3518	12.5
Kanred	12.0	1.3521	12.7	—	—	—
Akasabishirazu No. 1	12.7	1.3498	11.1	12.8	1.3503	11.5
Moscow 4	13.0	1.3512	12.1	—	—	—
Trappist	14.1	1.3478	9.9	15.1	1.3479	10.0
Ohio	16.4	1.3517	12.4	14.3	1.3504	11.6
Ro No. 56	12.7	1.3498	11.1	16.0	1.3504	11.6
Ro No. 57	—	—	—	15.3	1.3483	10.3
Average	13.4	1.3508	11.8	14.3	1.3499	11.3
			Spring Growing Habit			
Rouge prolifique barbe	13.3	1.3474	9.7	12.5	1.3479	10.0
Haynes	12.8	1.3464	9.0	13.6	1.3478	9.9
Ro No. 30	14.6	1.3480	10.1	15.7	1.3471	9.5
Meisaku	11.5	1.3464	9.0	14.0	1.3479	10.0
Wasekomugi	13.3	1.3457	8.5	13.2	1.3463	8.9
Manchuria No. 142	13.4	1.3471	9.5	16.5	1.3473	9.6
Average	13.2	1.3468	9.3	14.3	1.3474	9.7

*Temperature at reading 20°C.

In both the sand and pot cultures, the refractive indices of the winter varieties were nearly always greater than those of the spring varieties.

It will be observed from these results that the lack of differences

between the winter and spring varieties in the high temperature cultures, were probably due to characteristics of the winter wheats which are evident only under low temperature conditions.

In comparison of the moderate with the high temperature cultures, it was noted, on the whole, that the refractive indices of the former were distinctly greater than those of the latter, although the growth of the seedlings as indicated by height was about the same in both cultures.

Low temperature culture.—Seeds were sown in petri dishes on March 18, 1933. They were then germinated and grown in an incubator until about 7 cm in height when they were transferred to a room in which the temperature was maintained between 5° and 0° C. After 11 days the plants were treated as described above. The results are presented in Table 3.

TABLE 3.—*Relation between refractive indices and total solids in juice and the spring and winter growing habit in low temperature cultures.**

Variety	Sand culture		
	Average height of plants, cm	Refractive indices	Total solids, %
	Winter Growing Habit		
Ro No. 49	12.0	1.3569	15.7
Kanred	11.9	1.3568	15.6
Akasabishirazu No. 1	12.0	1.3513	12.2
Moscow 4	11.7	1.3552	14.7
Trappist	12.0	1.3504	11.6
Ohio	11.7	1.3566	15.5
Ro No. 56	11.9	1.3530	13.2
No No. 57	11.9	1.3504	11.6
Average	11.9	1.3538	13.8
	Spring Growing Habit		
Rouge prolifique barbe	11.5	1.3503	11.5
Haynes	10.5	1.3496	11.0
Ro No. 30	11.8	1.3534	13.5
Meisaku	11.5	1.3488	10.5
Wasekomugi	11.4	1.3479	10.0
Manchuria No. 142	13.0	1.3482	10.2
Average	11.6	1.3497	11.1

*Temperature at reading 20°C.

Approximately the same relationship was shown to occur in the low temperature cultures as in the moderate temperature cultures, namely, that the differences in the refractive indices of expressed juice were sufficient to distinguish between the winter growing habit and the spring growing habit of wheat. On the other hand, it will be noted that in the low temperature cultures the refractive indices of juice were much greater than in the moderate temperature cultures.

DISCUSSION

Gortner and Hoffman, cited by Gassner and Goeze (3),[3] in 1922 suggested the possibilities of making use of the refractometer for the study of plant juice. In 1926, for the first time, the refractometer was used for measuring winter hardiness in cereal crops by Newton and Brown, cited by Gassner and Goeze (3).

Thereafter, a series of studies was commenced by different investigators, especially by Martin (8); Roemer, Rudorf, and Lueg, cited from Gassner and Goeze (3); Thoenes (10); Balde (1); Fuchs (2); and Gassner and Goeze (3).

In these earlier investigations, however, there were no discussions about the spring and winter growing habit as one of the physico-chemical characters of wheat plants. The writer, having given special attention to this point, has summarized his own work as follows: When grown under low temperature conditions, the winter varieties as compared with the spring varieties are characterized by greater refractive indices in the expressed juice, on an average.

DETERMINATION OF HARDINESS IN WINTER VARIETIES

The relative winter hardiness of varieties may be determined by means of artificial refrigeration (5, 7, 9, 11). The low temperatures were secured with the Acme electric low temperature thermostat in which temperatures were controlled automatically.

METHODS

Fifteen seeds of each variety were sown in 3.5-inch clay pots filled with loamy clay soil on November 4, 1933. All plants were grown in a greenhouse (30° to 5° C) until about 10 cm in height under as nearly uniform conditions of cultivation as it was possible to obtain. They were then transferred to the hardening room maintained at a temperature varying between 9° and 0° C. After they had been hardened for 26 days, the seedlings were taken directly to the freezing thermostat and frozen at temperatures between a minimum of — 14.5° and a maximum of — 5.8° C for 40 hours.

Particular care was taken to have a uniform moisture supply in all pots at the time of freezing; hence before transferring to the freezing thermostat, the pots were made up to a moisture content of 75% on the dry-weight basis. Immediately after freezing, the plants were transferred to a warm room where they were allowed to recover.

The relative resistance of varieties to low temperatures was measured in two ways, *viz.*, by estimating the degree of injury of tissues apparently killed and by determining the percentage of plants killed.

The degree of tissue injury was estimated successively after freezing. The percentage of plants killed was calculated from the difference between the number of plants before placing in the thermostat and the number of live plants 30 days after freezing.

RESULTS

The hardiness rank determined as above, is given in Table 4.

As there are some differences between winter killing under field conditions and injury in the artificial freezing tests, the writer se-

[3]Figures in parenthesis refer to "Literature Cited", p. 899.

TABLE 4.—*Relative resistance of wheat varieties estimated by artificial refrigeration of plants hardened before freezing.*

Variety	Average height of plants, cm	Average number of leaves	Plant survival %
	Hardiest		
Ro No. 1	10.5	5	100
Ro No. 49	11.0	5	100
Moscow 4	14.0	4.5	100
	Hardy, Group I*		
Trappist	16.0	4	100
Akasabishirazu No. 1	16.5	5	100
Nōrin No. 2	23.5	5	100
	Hardy, Group II		
Pusa No. 6	17.0	4	87
Akakawa-aka	16.8	5	79
Riku-u No. 3	13.0	4	73
	Less Hardy, Group I		
Shiromansaku	16.5	5	60
Riku-u No. 5	12.2	5	60
Shirozaya No. 1	17.7	5	47
	Less Hardy, Group II		
Roterkolbenweizen	16.5	5	0
Hidawase	15.2	5	0
Nōrin No. 6	18.5	5	0
Beikoku No. 5	16.0	5	0
	Nonhardy		
Nishimura	15.5	4	0
Kōkai No. 197	14.5	5	0
Bōzu	16.0	5	0
Sanjaku No. 9	17.0	5	0
Igachikugo Oregon	16.2	4	0
Akadaruma-sai No. 1	15.0	5	0
Shirodaruma-sai No. 1	14.5	5	0
Murasakiaka	14.5	5	0
Nicton	14.0	5	0
Tōhoku No. 17	17.0	5	0
Shirokirisu No. 2	18.0	4	0
Nittawase	18.0	5	0
Shinchūnaga	14.2	4	0
Akadaruma	19.3	5	0
Eshimashinriki	20.0	4	0
Sōshū No. 58	16.2	4	0
Ooitakomugi No. 1	20.8	5	0
Hayabōzu	18.0	4	0
Wasekomugi (spring wheat)	19.5	4	0
Meisaku (spring wheat)	17.0	4	0

*Varieties under I are hardier than those under II.

lected several typical varieties for the following investigation, taking cold resistance under field conditions somewhat into consideration.

RELATION BETWEEN REFRACTIVE INDEX AND WINTER HARDINESS

MATERIALS AND METHODS

Because it was observed in preliminary experiments that the characteristics of the winter wheats make their appearance under sufficiently low temperature, the data used in this study were obtained on low temperature cultures.

Twenty seeds of each variety were sown in 3.5-inch petri dishes filled with quartz sand on February 23, 1934. They were germinated and grown in a warm room (30° to 7°C) without any fertilizers until about 10cm in height, then transferred to a cool room maintained at a temperature between 5° and 0° C. After 9 days in the cool room, the materials were taken to the laboratory and pressed.

At the same time, 15 seeds of each variety were also germinated in 3.5-inch clay pots filled with loamy clay soil under the same conditions of cultivation and with the other details of the test as described above.

However, in the present study, one of the duplicate samples of each variety was pressed after freezing in order to cause the disorganization of the protoplasm and to increase the permeability of the cell membranes by freezing.

RESULTS

Expressed juice from unfrozen samples.—The results obtained from unfrozen samples are given in Table 5.

From the data in Table 5 it will be noted that the hardy varieties as compared with the nonhardy varieties are characterized by greater refractive indices in general. This relationship was observed in both sand and pot cultures. In some instances, however the relation was not so distinct, and moreover, in two or three varieties the reverse was observed, showing greater refractive indices notwithstanding that they were estimated as less hardy.

Expressed juice from frozen samples.—In order to obtain frozen samples, seedlings were placed in the Acme electric low temperature thermostat and kept maintained in a frozen state.

Materials of the sand culture were left 34 hours in the thermostat at temperatures varying between — 8° and — 15° C, as follows: — 8° to — 10°, 8 hours; — 10° to — 13°, 15 hours; and — 13° to — 15°, 11 hours.

In the pot culture, 46 hours were spent for freezing, varying in temperature between — 8.5° and — 15° C, as follows: — 8.5° to — 9.5°, 3 hours; — 9.5° to — 12°, 4 hours; — 12° to — 14°, 23 hours; and — 14° to — 15°, 16 hours.

After freezing, the tissues which were apparently killed were used in this investigation. The results from frozen samples are shown in Table 6.

From the data in Table 6 it is evident that the hardy varieties had greater refractive indices than the nonhardy varieties just as in the case of the unfrozen samples.

In comparing juice obtained from frozen plants and that from unfrozen plants, Martin (8) reported that almost always greater refractive indices were observed in the juice from frozen plants. On the contrary, however, the evidence provided by this experiment shows

TABLE 5.—*Relation between refractive indices and total solids in juice and winter hardiness as determined from unfrozen samples.**

Variety	Sand culture			Pot culture		
	Average height of plants, cm	Refractive indices	Total solids %	Average height of plants, cm	Refractive indices	Total solids, %
			Hardiest			
Ro No. 1	10.1	1.3680	22.4	13.3	1.3614	18.5
Ro No. 49	11.8	1.3661	21.3	11.2	1.3639	20.0
Moscow 4	11.4	1.3644	20.3	12.8	1.3593	17.2
Average	11.1	1.3662	21.3	12.4	1.3615	18.6
			Hardy, Group I			
Trappist	13.1	1.3614	18.5	12.7	1.3579	16.3
Akasabishirazu No. 1	11.0	1.3639	20.0	14.5	1.3585	16.7
Nōrin No. 2	12.5	1.3590	17.0	15.7	1.3534	13.5
Average	12.2	1.3614	18.5	14.3	1.3566	15.5
			Hardy, Group II			
Akakawa-aka	12.5	1.3572	15.9	15.1	1.3551	14.6
Riku-u No. 3	11.7	1.3648	20.5	11.5	1.3608	18.1
Average	12.1	1.3610	18.2	13.3	1.3580	16.4
			Less Hardy, Group I			
Shiromansaku	11.1	1.3527	13.0	12.7	1.3554	14.8
Riku-u No. 5	11.9	1.3630	19 5	12.0	1.3607	18.0
Average	11.5	1.3579	16.3	12.4	1.3581	16.4
			Less Hardy, Group II			
Roterkolbenweizen	12.5	1.3583	16.6	—	—	—
Hidawase	11.5	1.3556	14.9	9.3	1.3538	13.7
Nōrin No. 6	10.6	1.3543	14.1	9.5	1.3536	13.6
Beikoku No. 5	11.0	1.3633	19.7	12.3	1.3581	16.5
Average	11.4	1.3579	16.3	10.4	1.3552	14.6
			Nonhardy			
Nishimura	11.3	1.3568	15.6	12.3	1.3550	14.5
Sanjaku No. 9	11.2	1.3559	15.1	10.0	1.3541	14.0
Igachikugo Oregon	11.1	1.3572	15.9	12.6	1.3536	13.6
Akadaruma-sai No. 1	11.5	1.3552	14.7	11.3	1.3525	12.9
Shirodaruma-sai No. 1	10.3	1.3590	17.0	9.5	1.3533	13.4
Shinchūnaga	10.8	1.3508	11.8	10.0	1.3530	13.2
Eshima-shinriki	10.2	1.3520	12.6	13.0	1.3523	12.8
Sōshū No. 58	10.4	1.3539	13.8	12.7	1.3530	13.2
Ooitakomugi No. 1	10.5	1.3531	13.3	11.7	1.3547	14.3
Hayabōzu	12.0	1.3539	13.8	12.2	1.3538	13.7
Average	10.9	1.3548	14.4	11.5	1.3535	13.6
Wasekomugi (spring wheat)	10.8	1.3501	11.4	15.7	1.3501	11.4

*Temperature at reading 20°C.

TABLE 6.—*Relation between refractive indices and total solids in juice and winter hardiness as determined from frozen samples.**

Variety	Sand culture			Pot culture		
	Average height of plants, cm	Refractive indices	Total solids %	Average height of plants, cm	Refractive indices	Total solids, %
			Hardiest			
Ro No. 1	10.1	1.3589	16.9	13.3	1.3572	15.9
Ro No. 49	11.8	1.3577	16.2	11.2	1.3575	16.1
Moscow 4	11.4	1.3599	17.5	12.8	1.3545	14.2
Average	11.1	1.3588	16.9	12.4	1.3564	15.4
			Hardy, Group I			
Trappist	13.1	1.3547	14.3	12.7	1.3510	12.0
Akasabishirazu No. 1	11.0	1.3571	15.8	14.5	1.3508	11.8
Nōrin No. 2	12.5	1.3539	13.8	15.7	1.3503	11.5
Average	12.2	1.3552	14.6	14.3	1.3507	11.8
			Hardy, Group II			
Akakawa-aka	12.5	1.3508	11.8	15.1	1.3520	12.6
Riku-u No. 3	11.7	1.3579	16.3	11.5	1.3558	15.0
Average	12.1	1.3544	14.1	13.3	1.3539	13.8
			Less Hardy, Group I			
Shiromansaku	11.1	1.3531	13.3	12.7	1.3496	11.0
Riku-u No. 5	11.9	1.3534	13.5	12.0	1.3541	14.0
Average	11.5	1.3533	13.4	12.4	1.3519	12.5
			Less Hardy, Group II			
Roterkolbenweizen	12.5	1.3533	13.4	---	----	---
Hidawase	11.5	1.3479	10.0	9.3	1.3473	9.6
Nōrin No. 6	10.6	1.3479	10.0	9.5	1.3488	10.5
Beikoku No. 5	11.0	1.3545	14.2	12.3	1.3496	11.0
Average	11.4	1.3509	11.9	10.4	1.3486	10.4
			Nonhardy			
Nishimura	11.3	1.3480	10.1	12.3	1.3460	8.7
Sanjaku No. 9	11.2	1.3500	11.3	10.0	1.3492	10.8
Igachikugo Oregon	11.1	1.3509	11.9	12.6	1.3489	10.6
Akadaruma-sai No. 1	11.5	1.3478	9.9	11.3	1.3479	10.0
Shirodaruma-sai No. 1	10.3	1.3499	11.2	9.5	1.3463	8.9
Shinchūnaga	10.8	1.3431	6.8	10.0	1.3473	9.6
Eshimashinriki	10.2	1.3504	11.6	13.0	1.3482	10.2
Sōshū No. 58	10.4	1.3483	10.3	12.7	1.3455	8.4
Ooitakomugi No. 1	10.5	1.3460	8.7	11.7	1.3471	9.5
Hayabōzu	12.0	1.3471	9.5	12.2	1.3467	9.2
Average	10.9	1.3482	10.1	11.5	1.3473	9.6
Wasekomugi (spring wheat)	10.8	1.3457	8.5	15.7	1.3467	9.2

*Temperature at reading 20°C.

that the juice from unfrozen plants has greater refractive indices than that from frozen plants, as reported recently by Gassner and Goeze (3).

DISCUSSION

Several studies with respect to the relation between the refractive indices of expressed juice and winter hardiness have been undertaken. Martin (8) reported that the hardier the variety, the greater was the refractive index on an average. Balde (1) mentioned that the hardier varieties seem to have the greater refractive indices in hardened conditions, even though it can not be accurately stated.

Gassner (4) and Gassner and Goeze (3) stated that the agreement between great refractive index and winter hardiness was in general good among the varieties in which marked differences had been observed in hardiness, but an exception to the agreement was mentioned in respect to the varieties in which the differences were not so apparent. The refractometer, therefore, could not be expected to serve as an accurate means for measuring winter hardiness.

The results of this study lead to the same conclusion as reached by previous investigators that refractive indices of expressed juice show a considerable relationship to winter hardiness, *viz.*, the hardy varieties have greater refractive indices than the nonhardy varieties under hardened conditions.

COMPARISON BETWEEN THE CONTENT OF TOTAL SOLIDS IN EXPRESSED JUICE OBTAINED BY THE REFRACTOMETER AND THE MONOSACCHARIDE CONTENT IN SEEDLING TISSUES DETERMINED BY CHEMICAL ANALYSIS

Among the physiological factors which frequently have been reported as associated with cold resistance, the sugar content in plant tissues has been recognized as most closely related to winter hardiness. As has already been noted, a significant correlation exists between the refractive index of expressed juice and winter hardiness, hence, it is of interest to ascertain the relationship between the total solids in expressed juice estimated by the refractometer and the monosaccharide content in seedling tissues as determined by chemical analysis.

MATERIALS AND METHODS

Varieties and methods of cultivation were the same as those employed in the previous experiments. Seeds were sown in 6-inch petri dishes filled with quartz sand on March 9, 1935, and three petri dishes with 70 seeds each were used for each variety. The seeds were germinated and grown in a warm room (25° to 9°C) without any fertilizers until about 7 to 11 cm in height, then transferred successively to a cool room which was maintained at a temperature between 5° and 0°C. After 5 days in the cool room, the plants were returned to the laboratory and the analysis was conducted.

The materials, consisting of the entire plants except the roots, were placed in beakers and dried to constant weight in an electric oven at 100°C. It was then crushed finely in a mortar by pestle, dissolved in water and made up to approximately a 1% solution.

The solution of the sample was boiled in the water-bath for 2 hours with frequent stirring. After boiling, the solution was cooled to 4°C and distilled water added until it reached exactly 1%, when the solution was filtered and the filtrate used for the estimation of the monosaccharides. The method employed for this determination was that of Kōketsu (6, 12), as follows:

A 0.1% solution of glucose was diluted with distilled water in regular order as 0.015%, 0.0125%, 0.01%, 0.0075%, 0.005%, etc. One cc of each diluted solution was placed in a test tube and 1 cc of the following modified Fehling-Soxhlet's solution was added. The A solution (recrystallised copper sulfate) was mixed with the B solution (Rochelle salt) in the rate of 1 to 2, instead of the normal ratio of 1:1, and the mixture was further diluted 8 times. The test tube was then heated in a bath of boiling water with constant stirring for exactly 5 minutes.

When the tube becomes cool, the cuprous oxide reduced by glucose will be deposited in such a manner that the deposition decreases progressively to a certain dilute concentration of glucose, beyond which it is not possible to estimate further the deposition of cuprous oxide.

Keeping this limit of glucose concentration in mind, 1% solution of the sample was treated as above, that is to say, the solution was diluted in regular order, the Fehling-Soxhlet's solution added, and the mixture heated for 5 minutes. After these treatments, the most dilute solution of the sample which acquired the Fehling-Soxhlet's reaction will then be obtained as above.

Finally, the writer calculated the amount of monosaccharides of the sample, considering that this dilute solution of the sample corresponds to the limiting (known) concentration of glucose.

EXPERIMENTAL RESULTS

The relationship between the monosaccharide content obtained by chemical analysis and the content of total solids in juice estimated by the refractometer in the previous experiments is shown in Table 7.

From the data in Table 7, the monosaccharide content in the tissues appears to be somewhat related to the total solids content of the juice as a whole. But it may not be justifiable to state that the monosaccharide content in tissues has an exact relation to the content of total solids in juice, when one considers the somewhat large irregularities that occurred between the order of the monosaccharide content and the content of total solids of these varieties.

DISCUSSION

From the standpoint of winter hardiness, at least so far as is known to the writer, not many studies have been hitherto reported on the comparison between the content of total solids in juice estimated by the refractometer and the monosaccharide content in seedling tissues determined by chemical analysis, except those of Balde's (1). According to Balde's investigations, there are no definite relationships found between them, even though the number of varieties used is considered to be too small to show sufficient reliable conclusions.

In the writer's experiments, approximately similar results were obtained, namely, the irregularities between the order of the monosaccharide content and the content of total solids were too large to find an accurate correlation between them.

TABLE 7.—*Comparison between the content of total solids in expressed juice obtained by the refractometer and the monosaccharide content in seedling tissues determined by chemical analysis.*

Variety	Total solids in juice, %					Monosaccharide in tissues, calculated from the dry-weight basis %
	From unfrozen sample		From frozen sample		Average	
	Petri dish culture	Pot culture	Petri dish culture	Pot culture		
			Hardiest			
Ro No. 1	22.4	18 5	16.9	15.9	18.4	10 7
Ro No. 49	21.3	20.0	16.2	16.1	18.4	10.0
Moscow 4	20.3	17 2	17.5	14.2	17.3	8.3
Average .					18 0	9 7
			Hardy, Group I			
Trappist. .	18 5	16.3	14.3	12.0	15.3	6 3
Akasabishirazu No. 1	20.0	16.7	15.8	11.8	16.1	8 3
Nōrin No. 2 .	17 0	13.5	13.8	11 5	14.0	7 1
Average					15.1	7 2
			Hardy, Group II			
Akakawa-aka . .	15.9	14 6	11.8	12.6	13.7	6.3
Riku-u No. 3 .	20 5	18.1	16.3	15.0	17.5	7.1
Average					15 6	6.7
			Less Hardy, Group I			
Riku-u No. 5	19.5	18 0	13.5	14 0	16.3	7 1
			Less Hardy, Group II			
Roterkolbenweizen.	16.6	—	13.4	—	15.0	5.0
Nōrin No. 6	14.1	13.6	10.0	10.5	12.1	6.3
Average					13.6	5.7
			Nonhardy			
Nishimura .	15.6	14.5	10.1	8.7	12.2	7.1
Sanjaku No. 9 .	15.1	14.0	11.3	10.8	12.8	5.0
Igachikugo Oregon.	15.9	13.6	11.9	10.6	13.0	7.1
Akadaruma-sai No. 1	14.7	12.9	9.9	10 0	11.9	8.3
Shinchūnaga	11.8	13.2	6.8	9.6	10.4	5.4
Eshimashinriki	12.6	12.8	11.6	10.2	11.8	5.0
Sōshū No. 58	13.8	13.2	10.3	8.4	11.4	5.4
Ooitakomugi No. 1.	13.3	14.3	8.7	9.5	11.5	4.2
Hayabozū.	13.8	13.7	9.5	9.2	11.6	5.0
Average . . .					11.8	5.8
Wasekomugi (spring wheat). . . .	11.4	11.4	8.5	9.2	10.1	3.6

SUMMARY

The studies described in this paper were undertaken to find the refractive indices of expressed juice as one of the physico-chemical

characters of wheat seedlings. The results obtained may be summarized as follows:

1. With respect to the relation between the refractive index and the winter and spring growing habit, the refractive indices of the winter varieties were greater than those of the spring varieties, on an average, when they are exposed to low temperature conditions before measurement.

2. In comparison between the three different temperature cultures, the lower the temperature the greater was the refractive index, thus indicating that the refractive indices of expressed juice are greatly affected by environmental factors.

3. With regard to the relationship between the refractive index and winter hardiness, the hardy varieties had greater refractive indices in general than the nonhardy varieties under hardened conditions.

4. Greater refractive indices were always observed in the juice from unfrozen plants as compared with that from frozen plants.

5. Within the limits of the present varietal investigations, an accurate correlation was not observed between the content of total solids in expressed juice estimated by the refractometer and the monosaccharide content in seedling tissues obtained by chemical analysis.

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INFLUENCE OF SOIL MANAGEMENT ON SOME PHYSICAL PROPERTIES OF A SOIL[1]

R. S. STAUFFER[2]

THAT poor systems of soil management are accompanied by rapid declines in crop yields and a reduction of essential plant nutrients in the soil has been shown conclusively by many studies. Much less information is available to show how the physical properties of the soil are affected by systems of cropping. It would be desirable to have more information of this kind.

The Morrow plats at the Illinois Agricultural Experiment Station at Urbana, present a good opportunity for such a study. The soil on which these plats are located was apparently fairly uniform when the experimental work was started and accurate records of treatment covering a long period of time are available. Furthermore, since very little soil has been removed by erosion, present physical differences in the surface soil can be studied as they could not be if much erosion had occurred.

DESCRIPTION OF THE PLATS

A complete history and description of the Morrow plats is given elsewhere (3),[3] therefore only a brief statement will be made here. The soil is Carrington silt loam, the natural productivity of which is probably somewhat above the average for this type. The cropping systems, with the exceptions noted in Table 1, have remained the same since the plats were first put in operation in 1876. No fertilizers were applied to any plats prior to 1904. Since that time treatments as indicated in Table 1 have been used.

TABLE 1.—*Treatment and cropping systems on the Morrow plats included in this study.*

Plat designation	Treatment*	Cropping system
3 NW	None	Continuous corn
3 SW	MLrP	Continuous corn
5 NW	None	Corn, oats, red clover†
5 SW	MLrP	Corn, oats, red clover†
Grass border	None	Same as plat 3 NW till 1904, since then in grass

*M = manure; L = limestone; rP = rock phosphate.
†Prior to 1899 the rotation was corn 2 years, oats, meadow (clover, timothy, or both) 2 years.

Where manure is applied the rate was 2 tons per acre per year until 1909. Since then the applications have been in direct proportion to the crops removed from the respective plats, that is, in amounts equal in weight to the air-dry weight of the crops removed. On the plats receiving limestone, 1,704 pounds per acre were applied in 1904 and 5 tons per acre in 1919. From 1904 to 1918 rock phosphate was applied at the rate of 600 pounds per acre annually. In 1919 the annual

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[3]Figures in parenthesis refer to "Literature Cited", p. 905.

rate was reduced to 200 pounds per acre, and at that time 2,800 pounds of rock phosphate were applied. This was done to bring the total application of rock phosphate up to four times the total amount of bone meal that had been added on some other plats with which comparisons were being made. In 1925 it was decided to discontinue applications of phosphate for an indefinite period.

The crop yields, which vary widely on the different plats according to the treatment, are given in Illinois Agricultural Experiment Station Bulletin 300, published in 1927, and in bulletins published annually since that time.

PLAN OF THE INVESTIGATION

Each plat, which is 2 rods wide and 4 rods long, was sampled with an auger at arbitrary depths in eight locations and the samples composited. In this study only the 0 to 6⅔, the 6⅔ to 13⅓, and the 13⅓ to 20 inch layers were included. Corresponding samples from the grass border near plat 3 NW were also included.

The determinations made and the methods used were as follows: Total carbon (7), inorganic carbon (2), mechanical analysis (6), moisture equivalent (1), dispersion ratio and erosion ratio by the method similar to Middleton's (5), except that 1 micron material obtained by mechanical analysis was considered the colloidal fraction and the percentage of material less than 0.05 millimeter was obtained by subtracting the percentage of sands from 100, water-holding capacity (4), and rate of percolation of water.

Since only small amounts of the soil samples were available and since it seemed desirable to secure some information regarding the relative rates of percolation, the following procedure was used: A 1½-centimeter layer of soil that would pass thru a 2-millimeter sieve was placed on a filter paper in a 6-centimeter Buechner funnel. The funnel containing the soil was placed in a beaker of distilled water so that the water outside the funnel was the same height as the top of the soil inside the funnel. After soaking for 1½ hours, the soil was drained, using suction from a filter pump, until the water ceased to flow from the soil. Then the funnel containing the wet soil was placed on a 500-cc graduated cylinder and water was added so that a constant head of 1 centimeter of water was maintained above the soil. A record was kept of the number of minutes required for each of eight successive 50-cc portions of water to drain thru the soil. The results given in Table 2 are averages of the eight. No suction was applied while the measurements were being taken.

Some of the soil, especially in the 6⅔ to 13⅓ and the 13⅓ to 20 inch layers, seemed to have formed rather resistant small clods on drying. It was thought that some worthwhile information might be obtained by letting the soils remain in a wet condition for a longer time and then repeating the percolation measurements. Therefore, after the first series of measurements, the wet soils were left in the funnels, which were covered for 24 hours, and the percolation measurements were repeated.

RESULTS AND DISCUSSION

The results on organic carbon (Fig. 1) show very definitely the effects of the different systems of soil management on the content of organic matter in the soil. The plat on which corn is grown every year without fertilizer has a considerably lower carbon content than the soil on the other plats. Where a corn, oats, clover rotation is followed and fertilizer is used, the organic carbon content is higher

TABLE 2.—*Data on soils of the Morrow plats.*

Plat	Sands, 2.0–.05 mm %	Clay, <.005 mm %	Colloid, <.001 mm %	Erosion ratio	Percolation* of soil saturated with water	
					1½ hrs.	24 hrs.
			0 to 6⅔ Inches			
3 NW	6.6	33.6	21.1	34.3	27.8	41.7
3 SW	5.7	32.1	21.8	26.3	28.3	37.6
5 NW	6.9	32.6	21.1	26.3	22.6	21.2
5 SW	5.0	33.3	21.3	20.1	21.6	20.9
Grass border	5.1	35.7	22.5	23.3	26.8	35.6
			6⅔ to 13⅓ Inches			
3 NW	4.7	39.6	25.6	15.6	12.3	12.3
3 SW	4.7	37.8	23.2	20.0	24.8	34.6
5 NW	6.2	36.2	21.8	18.2	12.5	12.6
5 SW	4.5	37.7	21.8	16.8	17.4	22.2
Grass border	3.9	38.5	23.0	20.7	20.0	20.6
			13⅓ to 20 Inches			
3 NW	5.5	43.2	30.4	21.2	20.9	19.7
3 SW	5.0	41.4	28.5	13.0	13.3	19.9
5 NW	7.0	39.3	24.2	20.7	10.4	9.9
5 SW	4.6	38.7	25.0	14.7	14.9	15.6
Grass border	3.2	39.5	25.1	13.3	12.4	11.0

*The figures on percolation are averages of the number of minutes required for 50 cc of water to drain thru the soil. Each figure is the average of eight trials.

than in the other plats in all cases and even higher than the grass border in the surface soil. However, the grass border seems to have a higher percentage of organic matter in the other layers of soil studied.

Moisture equivalent is an indication of the ability of a soil to retain moisture. It varies largely with the content of organic matter and the percentage of fine material. The results in Fig. 1 seem to bear out this statement.

The water-holding capacity of this soil seems to have been influenced very markedly by the cropping systems used. In the surface layer the range is from 56.5% in the unfertilized corn plat to 75.9% in the fertilized corn, oats, and clover plat, a difference of 19.4%. In the second layer of soil, the range is 12.0% and occurs between the same two plats. In the 13⅓ to 20-inch layer of soil, the water-holding capacity is still lowest in the unfertilized corn plat and highest in the corn, oats, clover plats with very small difference between the fertilized and the unfertilized plats of the latter. The range in this layer is 6.2%. The influence of the cropping system on the water-holding capacity is most marked in the surface soil and becomes less with depth. However, the effects are still apparent down to the 20-inch depth.

The dispersion ratios show distinct differences between the top layers of these plats, and these differences seem to be due to the treatments as well as to the cropping systems used. The unfertilized plat

on which corn has been grown every year has a dispersion ratio nearly twice as high as the fertilized plat on which a rotation of corn, oats, and clover has been grown. The surface soil of the grass border has a higher dispersion ratio than might have been expected, but the fact that this soil grew corn every year from 1876 to 1904 without fertilizer might help to explain the relatively high dispersion ratio. On the other hand, perhaps this soil on which a good system of soil management has been practiced has not become more easily dispersed because of being farmed.

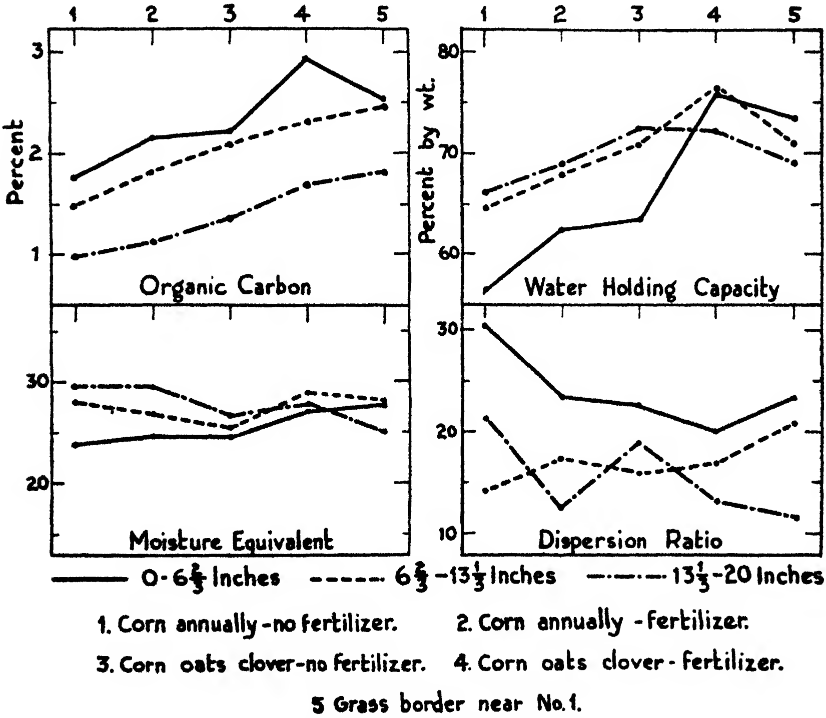

FIG. 1.—Effects of systems of farming on certain properties of the soils of the Morrow plats.

In the 6⅔ to 13⅓-inch layer of soil, the dispersion ratio is lower in every instance than in the corresponding surface soil. The drop in case of the unfertilized corn plat is very marked. The only reason apparent at this time why this difference should be so much greater than in the other plats is that there seems to be a somewhat greater accumulation of fine material in this layer of soil in this plat.

In the 13⅓ to 20-inch layer of soil, the dispersion ratios still differ quite widely for the different plats. They are fairly consistent with the results on the surface soils with the exception of the corn plat which has received fertilizer. Further investigation might reveal why the dispersion ratio is so low in this case, but no reason is apparent at this time.

The erosion ratios tell essentially the same story as the dispersion ratios and will not be discussed further.

The mechanical analyses indicate that the soil on which these plats are located is fairly uniform in physical composition. The range in sand content of the surface soil is 1.9%. The greatest range in the percentage of sand is 3.8% and occurs in the 13⅓ to 20-inch layer of soil. The clay content of the various plats is likewise fairly uniform. However, there appears to be more accumulation of the finer portion of the clay fraction in the illuvial horizon of the continuous corn plats than in the other plats This is most marked in the case of the corn plat which has not received fertilizer. Further study of this point is necessary before any definite conclusions should be drawn.

Since the results on percolation were secured on small samples of soil in which the natural structure had been at least partially destroyed, care is necessary in making interpretations. Nevertheless, several points worth noting seem to be indicated by the results.

In the first series of measurements, after the soil had remained in a wet condition for 1½ hours, percolation in the surface soils was slowest in the samples from the plats on which corn is grown every year, although it was very little faster in case of the grass border. After the soil was saturated with water for 24 hours, there were very much greater differences in the rates of percolation among the surface soils of the different plats. The soil from the corn, oats, and clover plats, both fertilized and unfertilized, permitted just as rapid percolation as in the first series of measurements In fact, the results indicate that it was slightly more rapid. The surface soils from the plats growing corn annually, and also from the grass border, drained much more slowly after the soil had soaked for 24 hours than after it had been soaked for 1½ hours. It would seem that the results secured on the soils after being in a wet condition for the longer period of time would more nearly compare with their behavior under natural conditions since under those conditions they would not ordinarily have been air-dry.

Some interesting points are suggested by the results on percolation secured on the samples from the 6⅔ to 13⅓-inch layer of soil. Except with the soil from the fertilized corn, oats, and clover plat, which had been kept in a wet condition for 24 hours before measurements were taken, percolation was more rapid than in the corresponding surface soils. The results, however, are not in the same order as in the surface soils. The samples from the unfertilized corn plat and the unfertilized corn, oats, and clover plat drained more rapidly than the soils from the unfertilized plats. Keeping the soil in a wet condition for 24 hours before making measurements had little, if any, effect on the rate of percolation of the unfertilized plats or the grass border. It had some effect, however, on slowing down the rate of percolation in the soils from the fertilized plats. The results seem to indicate that the fertilizer treatments received by these plats have had some effect on the drainage properties of the soils in the 6⅔ to 13⅓-inch layer.

In the samples from the 13⅓ to 20 inch layer of soil, percolation was still more rapid than in the 6⅔ to 13⅓ inch layer, except in

case of the unfertilized continuous corn plat which was slower. There is some indication that in this layer of soil also, the fertilized plats show a relatively slower rate of percolation than the unfertilized plats, especially after the soils were saturated with water for 24 hours. This seems to be less marked, however, than in the 6⅔ to 13⅓ inch layer of soil.

SUMMARY AND CONCLUSIONS

1. In the 0 to 6⅔ inch layer of the soils included in this study, plat 3 NW, the unfertilized continuous corn plat, has the lowest organic carbon content, the lowest moisture equivalent, the highest dispersion and erosion ratios, the lowest water-holding capacity, and, with one exception, the slowest rate of percolation. Plat 3 SW showed a slightly slower rate of percolation after the soil had been saturated with water for 1½ hours. In this same layer of soil, plat 5 SW, the corn, oats, and clover plat on which fertilizer and lime have been used, has the highest organic carbon content, the lowest dispersion and erosion ratios, the highest water-holding capacity, the most rapid rate of percolation, and the highest moisture equivalent except the grass border, which has a slightly higher moisture equivalent.

2. In the 6⅔ to 13⅓ inch layer of soil, the results are quite different than in the surface layer. The unfertilized corn plat has a relatively low dispersion ratio and permits the most rapid percolation of water. The results presented in Fig. 1 and Table 2 indicate that the same is true for the unfertilized corn, oats, and clover plat in this same layer of soil.

3. In the 13⅓ to 20 inch layer of soil, the unfertilized corn plat occupies the same position among the different samples as in the surface layer, except that it has a relatively high moisture equivalent. This may be accounted for by the fact that it contains a higher percentage of material of the size of clay and finer. The fertilized corn plat has a relatively low dispersion ratio in this layer of soil. No reason for this is apparent at this time.

4. Poor systems of cropping and soil treatment are not only accompanied by rapid declines in crop yields and a decrease in plant nutrients, but also by changes in the physical condition of the soil. In the surface soil especially these changes are undesirable.

5. It appears from the results reported here that soil on which poor cropping systems have been followed, and there are many such areas in Illinois, are much more subject to destruction by erosion than soils on which good systems have been followed.

6. The results also indicate that good physical condition of a soil, such as the one studied here, can be maintained if good systems of cropping and management are followed.

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THE SPURGE NETTLE[1]

Ralph T. Stewart, R. G. Reeves, and L. G. Jones[2]

THE spurge nettle (*Jatropha texana*), also frequently called bull nettle, tread softly, and *Malo mujer*, is a plant well known to many persons as a thorny or prickly weed that has a painful sting. However, investigations by the authors show that it possesses certain interesting peculiarities not generally known. The purpose of this paper, therefore, is to call attention to some of its less known characteristics, and to report results of preliminary experiments for its control.

THE ROOT OF THE PLANT

A search through the literature concerning the species indicates that most botanists who have discussed the spurge nettle have given rather complete descriptions of the characteristics of the aerial parts of the plant, but the discussions of the roots have been quite brief and do not satisfactorily describe the underground parts. At least the root system has been given minor consideration in all descriptions of the plant which have been found.

Before attempting to describe the roots, it is desired to review certain literature on the subject. Robinson and Fernald (7)[3] describe *Jatropha stimulosa*, a form closely related to *J. texana*, as having long perennial roots. Wooton and Standley (10) state that *Jatropha* has thick tuberous roots. Coulter (5) writes that *J. stimulosa* is an herbaceous plant having a long perennial root. Bailey (1) discusses the aerial parts of *J. stimulosa* but does not mention its roots. Britton and Brown (3) refer to a form of *Jatropha* as *Cnidoscolus stimulosa* and state that it is a perennial plant with a stout root. Schulz (8) refers to *J. texana* as the *Malo mujer* (bad woman) among plants. She describes the tops of the plant but does not mention its roots. Small (9) describes the top of *C. texanus*, but does not mention its roots. In describing *J. stimulosa*, Georgia (6) states that, "The tough, woody, branching roots of this plant often penetrate the soil to a depth of 3 to 5 feet taking to themselves what food and moisture is to be found." Hers is the most complete description of the root found. Other references have been reviewed but none of them give the reader a definite idea of the root system of the plant.

Although the root of the spurge nettle does not seem to be adequately described, certain individuals are known to be familiar with its characteristics. The writers' attention was first called to the size of the roots of this plant by Dr. U. R. Gore, formerly Instructor in the Biology Department, Texas A. & M. College. The root system of the plant has also been discussed with certain other individuals who knew something of its enormous size. Not until the Farmers' Short Course at A. & M. College in 1934, however, was it realized that so few people knew of the gigantic roots of the spurge nettle.

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[1]Contributions from the Departments of Agronomy and Biology, Agricultural and Mechanical College of Texas, College Station, Tex. Received for publication June 29, 1936.

[2]Associate Professor of Agronomy, Professor of Biology, and Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 913.

From discussions during one of the meetings of the Short Course the authors became interested and decided to make certain studies of the plant and its habits. A brief report of the results of these studies was given before the Texas Academy of Science in November, 1934.

An idea of the plant may be obtained from photographs made of suitable specimens. Fig 1 is a photograph showing all of the parts of a medium to large plant The top of the root was found to be 2 feet, 3 inches below the surface of the ground. At 3 feet, 8 inches the first branch root was found. At 3 feet, 9 inches below the surface the lower part of the root forked. Below the 5-foot depth only small branch roots 1/2 to 1 inch in diameter were found The root was cut off at 6 feet, 5 inches below the surface of the ground Its largest diameter was 7¾ inches

The portion of the plant taken from below the surface of the soil weighed 44 pounds. The aboveground portion weighed only 3.3 pounds No small fibrous feeding roots were found in the area where the digging was done. The root was quite woody, but fleshy enough to be cut easily with a spade. When injured, large quantities of a milky, sticky fluid flowed freely from the wounds

FIG. 1.—Photograph showing aerial and underground parts of the spurge nettle. A meter stick is shown parallel with the root. The crown of the root at the upper end of the meter stick was 2 feet, 3 inches below the surface of the ground.

After the root shown in Fig. 1 was photographed, it was sawed in two in order to try to count the growth rings Unfortunately, they were not definite and little could be determined concerning the age of the plant. The freshly cut roots of this plant impart odors similar to the fragrance of its flowers.

Fig. 2 shows something of the development of the root of the spurge nettle. The two plants on the right are apparently seedlings, the third plant 1 year old, and the fourth and fifth plants 3 years old. No close estimate can be made con-

cerning the age of the three plants on the left. It is highly probable, however, that the plants are arranged from right to left according to age, the plant on the right being the youngest and the one on the left the oldest.

The double cord across the top shows the surface of the ground line on each of the plants. The roots of the plants have something of the shape of a carrot, but instead of the upper part of the root being at the surface of the ground, it occurs some distance below. The single cord stretched diagonally across the picture shows the area of transition between root and stem. In the smallest plant the top of the root was approximately 6 inches below the surface of the ground. The top of the large root on the left of the picture occurred approximately 16 inches below the surface of the ground. The top of the root shown in Fig. 1 occurred 27 inches below the surface of the ground. It is an interesting fact that as the root grows older, it sinks farther below the surface of the soil.

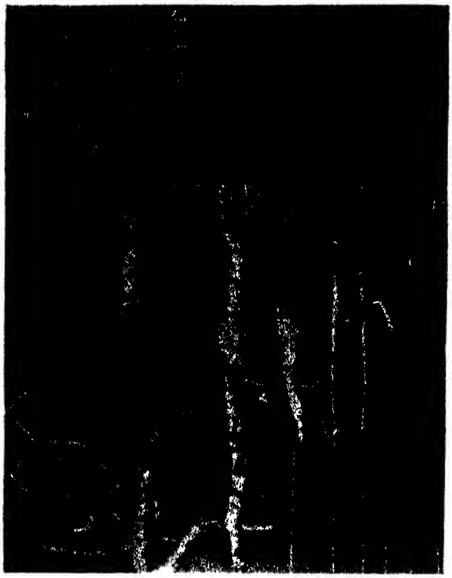

FIG. 2.—Photograph showing the size and shape of the root of the spurge nettle. The double cord across the top of the picture shows where the surface of the ground occurred. The single cord stretched diagonally across the picture shows the upper limits of the roots. The table upon which the plants are mounted is 6 feet long.

The first observations led the authors to believe that perhaps the soil had gradually filled in about the plants leaving the crown of the root deep under the surface. However, later observations made on plants growing on the top of hills and on almost level ground showed that the occurrence of the crown of the root deep under the ground is a natural characteristic of the plant and not a result of soil filling in about the plant. Just why the crown of the root should continually grow deeper into the soil as the plant grows older cannot be fully explained at this time. It is possible, however, that during early growth, elongation takes place very rapidly and in later development the root contracts and pulls the crown down into the soil. The top of the enlargement of the underground portion is the crown of the root and the portion between the crown and the surface of the soil is, in reality, stem. This conclusion is readily drawn because of the presence of nodes and internodes on the smaller upper part. Further studies of the plant may show this to be an odd and extreme case of a contractile root.

THE TOP OR AERIAL PART OF THE PLANT

As stated earlier, the aerial part of the spurge nettle has been described by many writers. It is thought, however, that a brief statement of a few peculiarities not previously mentioned will be interesting. Fig. 3 shows a close-up view of one of the plants. The spiny character of the plant can be observed in the photograph. A seed pod partially burst open can be seen in the center of the picture. Within a few hours the pod will burst completely and three seeds will be thrown to the ground to produce new plants.

FIG. 3.—A close-up view of the aerial portion of the spurge nettle. Note the shape of the leaves, the spines on the leaves and stems, and the seed pod (center) beginning to open.

In Fig. 4 is shown a magnified view of two spines from the plant. In A, the spine is shown as it occurs on the plant. In B, the spine is shown after it has pricked an object, such as some part of the body. The spine normally has a small gland on its tip and upon pricking any part of the body the gland is broken off and remains within the victim, causing extreme pain and itching. The gland was found to be filled with a fluid which no doubt is largely responsible for the unpleasant sting characteristic of thorns.

Where the plant occurs, it is considered to be a most troublesome weed. Mr. C. H. McDowell, Superintendent of the Iowa Park Substation of the Texas Agricultural Experiment Station, reported that horses grazing in pastures where the plants are plentiful often swell on the pasterns to twice their normal size as a result of stings made by this weed. It has also been reported that chickens running over these plants often become sore-footed and cannot walk.

ERADICATION STUDIES

From the standpoint of eradication, a plant with such a supply of reserve food in its underground parts is difficult to kill by cutting the tops to starve the roots. During the past year, the authors have made some preliminary experiments to determine possibilities of eradicating the spurge nettle. The eradication of the plant by using a poison seemed to offer the greatest possibilities; therefore, the following chemicals were tried: Sulfuric acid, Atlacide, and arsenic. The chemicals were applied to the plants in a number of different ways. The results of the chemical treatments are reported briefly.

FIG. 4.—A greatly enlarged photograph of two of the spines on the leaves and stems of the spurge nettle. A, view of a spine as it occurs on the plant. Note the small knoblike gland on its tip. B, view of a spine after it has pricked some object such as one's hand, leg, or foot. Note that the small knoblike gland has been broken off. The gland remains in the flesh of the victim causing a sting or itchy pain.

SULFURIC ACID

Sulfuric acid was applied to the plants in two concentrations, *viz.*, in 10% and in 15% solutions. The solutions were applied by spraying the tops of the plants thoroughly, by removing the tops of the plants at the surface of the ground and saturating the freshly cut stumps with the solutions, and by removing the top of the plants to a depth of 6 inches below the surface of the ground and saturating the stumps with the solutions. In every case the sulfuric acid treatments killed that portion of the whole plant above the ground, but they had little or no effect upon the vigor of the roots.

ATLACIDE

Plants were sprayed with solutions made by dissolving 1 and 2 pounds of Atlacide in 1 gallon of water. Other treatments were made by removing the tops of the plants at the surface of the ground and applying varying amounts of the powdered Atlacide (70, 50, 30, and 20 grams) to the stumps. Before applying the Atlacide powder the stumps were bruised or cut with a spade to make them bleed and dissolve the Atlacide.

Spraying the tops of the plants one time with either of the solutions of Atlacide killed that portion of the plant above the ground but seemed to have little or no effect on the portion of the plant below the ground. The heavier applications of Atlacide in the powdered form seemed to weaken the portion of the plant below the surface of the ground when applied to the freshly cut stumps.

ARSENICALS

Arsenical mixtures have long been used to kill trees and other plants. It was thought possible that some of the mixtures might be valuable to eradicate the spurge nettle. To determine the value of arsenical poisons, two different formulae were chosen. Formula No. 1, proposed by Cope and Spaeth (4), was made up by dissolving 2 pounds of white arsenic and ½ pound of commercial lye in 1 gallon of water. Formula No. 2, suggested by Boyd (2), was made up by dissolving 1 pound of white arsenic and 2 pounds of commercial lye in 2 gallons of water. Enough soil was removed from around the plant to expose the crown of the root. A hole 2½ to 3 inches deep was bored into the root with a ¾ inch auger. Twenty-five cc of the solution to be used was poured into the hole in the root. The root was then covered with soil to prevent stock grazing in the pasture from being poisoned. Five plants were treated with each solution. Four of the plants treated with formula No. 1 died and the roots completely decayed in less than a year. Only one of the plants treated with formula No. 2 died. From these results, arsenic mixed with a small amount of commercial lye would seem to be a promising poison to use in eradicating the spurge nettle.

ERADICATION BY INVERTING A TIN CAN OVER THE STUMP OF EACH PLANT

Mr. T. P. Porter, a senior agronomy student at Texas A. & M. College, told the authors that he had been successful in eradicating the spurge nettle by removing the top of the plant and inverting a tin can over the stump. This method seemed to have merit, and was therefore given a trial. On July 21, 1935, the authors removed the tops from nine medium to large plants. A 1-gallon tin can was inverted over the stumps of eight of them, the ninth plant being left uncovered as a check.

On June 7, 1936, the tin cans were removed to determine the effect of the can on the plants. All but one of the stumps had sprouted. The new growth had almost completely filled the can, but no shoots had grown around the can. A study of the sprouts under the can showed that the stumps had been putting out new shoots during most of the year, but that before they attained much size they were attacked by a white fungus and many small insects which caused them to die and rot. The stump which did not sprout was cut off 8 inches below the surface of the ground. An examination showed that it was one of the smaller plants and that it had been cut off below the crown of the root which probably explains why it did not sprout. Only a small portion of its root was alive.

After remaining under the cans for almost 11 months only the one plant mentioned above was dead, but the indications were that all the other stumps would eventually die. The cans were placed back over the stumps. It is planned to examine the stumps from time to time to determine how long it will require to starve the roots.

DISCUSSION

The characteristics of the spurge nettle are of interest in several ways. As a weed, a knowledge of its growth habits will likely be helpful in finding a satisfactory method for its eradication.

The roots of spurge nettle offer a possibility of use in some commercial way. Bailey (1) states that there are several species of the genus *Jatropha* which are more or less useful in medicine. The oil of one species, *J. cureas*, is used as a purgative, for cooking, and for soapmaking. The seeds of spurge nettle are sometimes used as food, and farmers have reported that the roots are eaten by hogs. It is also known that the species of *Jatropha* are closely related to the castor bean (*Ricinus communis*), a plant widely used in medicine, and that tapioca is made from the fleshy root of the cassava plant (*Manihot utilissima*), a close relative which is cultivated widely in tropical America.

The plant normally grows on very poor sandy soils, frequently the Norfolk series. It seems to be little affected by drought and remains green when other plants wither and die.

Physiologically the plant is unique. Any plant that produces such an enormous root and such small aerial parts must either require many years for growth, or the plant must be very efficient in its photosynthetic activities.

Further studies on the eradication of the plant and its growth habits are being made.

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THE RATE OF DECOMPOSITION OF VARIOUS PLANT MATERIALS IN SOILS[1]

H. C. MILLAR, F. B. SMITH, AND P. E. BROWN[2]

THE factors affecting the growth and activity of the soil microorganisms also influence the rate of decomposition of organic matter. Experiments have shown that the kind of organic matter and other nutrient constituents, particularly nitrogen, are important factors in determining the rate of decomposition. In most cases, however, this has been found to be closely related to the nitrogen content of the organic matter. For example, materials of a narrow carbon-nitrogen ratio, such as that of most legumes, decompose more rapidly than those having a wide carbon-nitrogen ratio, such as the cereal straws and other materials of a woody nature. However, few of these experiments have been conducted over a sufficiently long period of time to characterize completely the decomposition process and those experiments (1, 4)[3] which have been carried long enough have included only a few of the common crop materials.

The purpose of the work reported in this paper was to determine the rate of decomposition of a number of plant materials commonly found on the farm and to investigate the relationship of initial carbon and nitrogen content to the rate of decomposition over a relatively long period.

PROCEDURE

The decomposition of organic matter in the soil is primarily a biological process and carbon dioxide is one of the end-products which can be conveniently measured. Practically all of the carbon dioxide evolved from soils which are not supporting a crop is derived from this source. Consequently, carbon dioxide production has long been regarded as a good index of organic matter decomposition in soils. In these experiments the various materials were added to soils and the production of carbon dioxide determined at regular intervals for a period of 6 months.

Mature oat straw, wheat straw, sudan grass, cane sorghum, flax, cornstalks, millet, hemp, soybeans, alfalfa, sweet clover, and red clover grown on the Agronomy Farm during 1934 were harvested and dried. The materials were passed through a hammer mill, ground to pass a 40-mesh screen, and each sample thoroughly mixed. Total carbon was determined by the dry combustion method and total nitrogen by the Gunning-Hibbard method. The production of carbon dioxide in soils treated with four of these materials was determined in a preliminary experiment by the respiration chamber method (5) for comparison with the aspiration method. Further studies on the accuracy of the respiration chamber method were made in another experiment and finally the rate of decomposition of each of the materials listed above was determined by the respiration chamber method.

[1]Jour. Paper J-367 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 446. Received for publication July 28, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 923.

RESULTS

COMPARISON OF RESPIRATION CHAMBER METHOD AND ASPIRATION METHOD FOR DETERMINING CARBON DIOXIDE PRODUCTION IN SOILS

Eight 300-gram portions of Dickinson fine sandy loam were weighed into 1-liter Erlenmeyer flasks. The soil was slightly acid in reaction and sufficient finely ground limestone was added to neutralize the acidity. Duplicate flasks were treated with wheat straw, sudan grass, alfalfa, and sweet clover at the rate of 0.3%. The moisture content of the soils was adjusted to 23% by the addition of distilled water

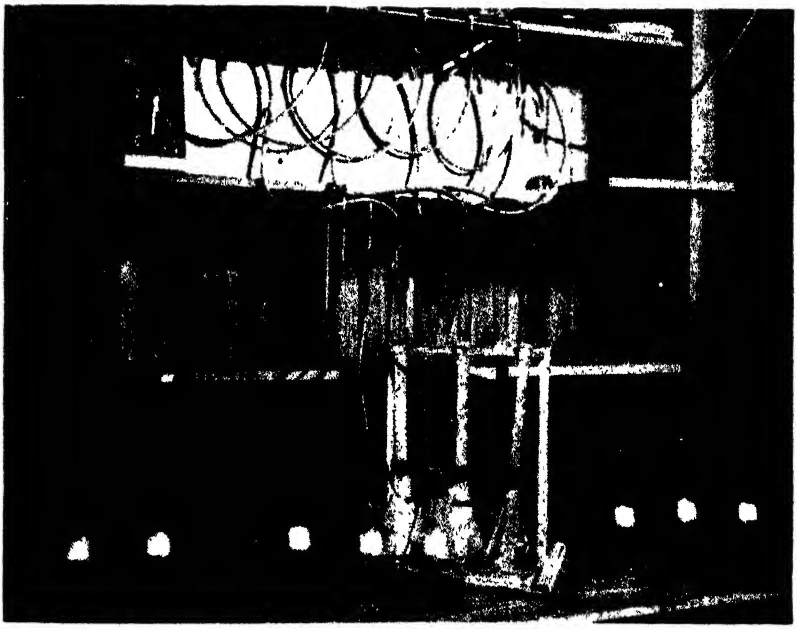

FIG. 1.—Apparatus for determining carbon dioxide produced in the soil.

and the flasks placed in the incubator at a temperature of 25° C. Carbon dioxide production was determined at intervals by aerating the flasks with carbon dioxide-free air and absorbing the carbon dioxide in standard KOH. The apparatus used for producing the carbon dioxide-free air consisted of a 2-liter bottle half filled with NaOH connected to a bead tower and an air-lift pump to circulate the NaOH. The washed air was taken from the reagent bottle through the remainder of the train (Fig. 1) with a minimum suction force. The method of washing the air used in this aspiration method has an advantage over other methods in that it requires a minimum of suction, no back-pressure is developed during a determination, it is easier to maintain the same rate of aspiration of the different flasks, and it does not require frequent renewal of the NaOH.

Eight 300-gram portions of Dickinson fine sandy loam which had been treated with sufficient finely ground limestone to neutralize the acidity were weighed into 400-cc beakers. Duplicate beakers of soil were treated with wheat straw, sudan grass, alfalfa, and sweet clover at the rate of 0.3%. The moisture content of the soils was adjusted at 23% by the addition of distilled water. The beakers were placed in the respiration chambers which were kept in the laboratory at about 25° C. The carbon dioxide production was determined at the same intervals as in the aspiration method. The results obtained by the two methods are presented in Table 1.

TABLE 1.—*Comparison of methods for determining carbon dioxide production in soils (mgm CO_2).*

Time in hours	Respiration chamber method				Aspiration method			
	Wheat straw	Sudan grass	Alfalfa	Sweet clover	Wheat straw	Sudan grass	Alfalfa	Sweet clover
12	19.0	32.2	44.7	26.4	56.3	77.6	78.5	95.1
24	52.8	79.3	104.5	64.6	96.2	152.3	178.4	203.1
36	79.8	109.4	157.7	100.7	136.5	202.2	243.0	272.5
48	105.8	159.0	199.5	129.0	156.5	249.7	316.3	358.8
60	132.0	201.3	266.4	176.8	214.2	296.0	369.6	409.8
72	160.1	235.3	314.4	222.1	245.2	331.0	425.6	467.0
96	220.0	216.5	412.1	311.2	312.4	374.3	501.9	547.5
120	279.8	389.1	501.4	395.2	375.4	475.9	568.0	612.7
144	335.5	455.5	575.6	473.3	428.1	549.7	629.9	685.4
192	432.0	559.0	681.0	537.7	527.2	653.4	723.8	791.9
288	590.4	731.7	844.0	759.9	673.7	810.8	857.6	945.4
384	732.1	878.8	978.0	981.8	784.7	922.1	955.2	1,051.9
528	929.7	1,064.8	1,137.0	1,175.5	941.5	1,064.4	1,093.4	1,183.4
624	1,025.6	1,158.2	1,209.8	1,280.6	1,037.2	1,147.9	1,169.5	1,261.7

The data in the table show that the rate of decomposition was more rapid in the beginning of the experiment by the aspiration method than by the respiration chamber method. However, after about 24 to 26 days the total carbon dioxide evolved from the soils treated with the same kind of materials was about the same with the two methods. The more rapid oxidation of the organic matter in the beginning of the experiment by the aspiration method was probably caused by the aeration of the soil in the aspiration process.

FURTHER STUDIES ON RESPIRATION CHAMBER METHOD OF DETERMINING CARBON DIOXIDE PRODUCTION IN SOILS

Preliminary studies on the respiration chamber method showed that a film forms over the surface of the barium hydroxide in the presence of carbon dioxide. This film breaks and settles when the solution is shaken. A study was made to determine the effect of the film upon the carbon dioxide absorption in the chamber. Two series of soils containing 24 samples each were treated with 0.3% of the plant materials as shown in Table 2. The soils were placed in the chambers. During the course of the experiment the chambers containing one series of samples were rotated and the chambers containing the other

samples were not rotated. The total carbon dioxide evolved after 180 hours was determined for each series. The carbon dioxide and oxygen content of the atmosphere within the chambers of the series "not rotated" was measured by means of a Haldane (3) gas analysis apparatus. The results obtained are shown in Table 2.

TABLE 2.—*Carbon dioxide absorption under different conditions by the chamber method (mgm CO_2 after 180 hours).*

Materials	Rotated	Not rotated	Carbon dioxide %	Oxygen %
Oat straw	498.08	487.96	Trace	20.8
	498.63	498.96	Trace	19.9
Wheat straw	465.74	450.34	Trace	20.1
	421.68	465.30	Trace	20.0
Sudan grass	542.08	556.10	Trace	20.4
	545.82	537.02	Trace	20.2
Cane sorghum	517.44	512.50	Trace	20.2
	518.54	548.02	Trace	20.3
Flax	581.68	585.94	Trace	20.5
	591.80	598.40	Trace	20.5
Cornstalks	482.22	507.76	Trace	20.2
	503.36	535.46	Trace	19.8
Millet	599.06	598.18	Trace	20.3
	579 26	524.04	Trace	20.5
Hemp	517.00	579.48	Trace	19.8
	510.84	533.28	Trace	20.1
Soybeans	550.88	557.70	Trace	20.5
	538.01	562.10	Trace	20.3
Alfalfa	617.54	621.06	Trace	20.3
	623.06	632.94	Trace	20.1
Sweet clover	692.12	700.04	Trace	19.7
	678.04	794.44	Trace	20.4
Red clover	586.70	573.54	Trace	20.1
	561.00	572.66	Trace	20.2

The data show that the difference between the amounts of carbon dioxide in the two series was not larger than the difference between duplicate treatments. This indicates that all of the carbon dioxide evolved was being absorbed when the chambers were stationary.

An analysis of the atmosphere within the chamber during the experiment showed no accumulation of carbon dioxide and a normal content of oxygen.

The results seem to justify the conclusion that the respiration chamber method is accurate and it certainly has distinct advantages over the aspiration method since less equipment is required and the determinations can be made more rapidly.

RATE OF DECOMPOSITION OF VARIOUS PLANT MATERIALS IN SOILS

The rate of decomposition of the plant materials used in the preliminary experiment was studied over a longer period by determining the evolution of carbon dioxide from soil treated with the different materials. The organic materials were added to the soil at the rate of 0.9 gram per 300 grams of soil. The moisture content of the soils was adjusted to 18% and carbon dioxide determinations were made each 12 hours during the first 2 days. As the rate of carbon dioxide evolution decreased, the determinations were made at longer intervals. During the second period, 2 to 8 days, the determinations were made every 24 hours. During the third and fourth periods, 8 to 120 days, the determinations of carbon dioxide were made each 2 days, and finally, in the fifth period, the determinations were made at intervals of 7 days. The study was continued for 190 days. The results obtained are presented in Tables 3 and 4 and Figs. 2 and 3.

TABLE 3.—*Carbon dioxide produced from soils treated with plant materials.*

Plant materials	Carbon %	Nitrogen %	Average mgm of carbon dioxide per 24 hours				
			Period I, 0–2 days	Period II, 3–8 days	Period III, 9–26 days	Period IV, 27–120 days	Period V, 121–190 days
Check	0.00	0.00	21.00	10.66	6.72	5.15	3.92
Oat straw	39.00	0.61	82.20	54.83	23.34	8.78	3.96
Wheat straw	38.27	0.50	83.40	48.53	24.26	8.68	3.89
Sudan grass	40.30	1.06	119.84	49.85	21.31	8.11	3.52
Cane sorghum	39.11	0.87	116.54	49.55	22.12	8.15	3.78
Flax	39.70	1.73	143.44	51.33	19.40	7.57	3.78
Corn stalks	38.11	1.20	119.24	47.30	24.30	8.21	3.69
Millet	38.47	1.17	138.10	47.58	21.23	8.34	4.26
Hemp	38.92	0.88	119.10	53.08	24.37	9.47	3.97
Soybeans	36.41	1.85	150.44	43.15	16.90	6.97	3.49
Alfalfa	38.19	3.07	179.64	44.96	16.30	7.42	3.96
Sweet clover	38.35	3.14	212.40	46.23	15.90	6.88	3.28
Red clover	39.14	2.20	143.44	47.75	18.48	7.33	3.55

TABLE 4.—*Average carbon dioxide evolved from soils treated with plant materials.*

Period	Mgm of carbon dioxide per 24 hours		
	Check	Non-legumes	Legumes
I, 0–2 days	21.00	115.10	171.22
II, 3–8 days	10.66	50.25	45.52
III, 9–26 days	6.72	22.54	16.90
IV, 27–120 days	5.15	8.35	7.15
V, 121–190 days	3.92	3.80	3.57

The data in Table 3 show the average carbon dioxide production per 24 hours in the soils treated with the different plant materials during the five periods.

An analysis of variance of the data showed that the evolution of carbon dioxide from the treated soils was significantly greater than that of the check soil in the first four periods, but the differences were not significant during the fifth period. The soil treated with sweet

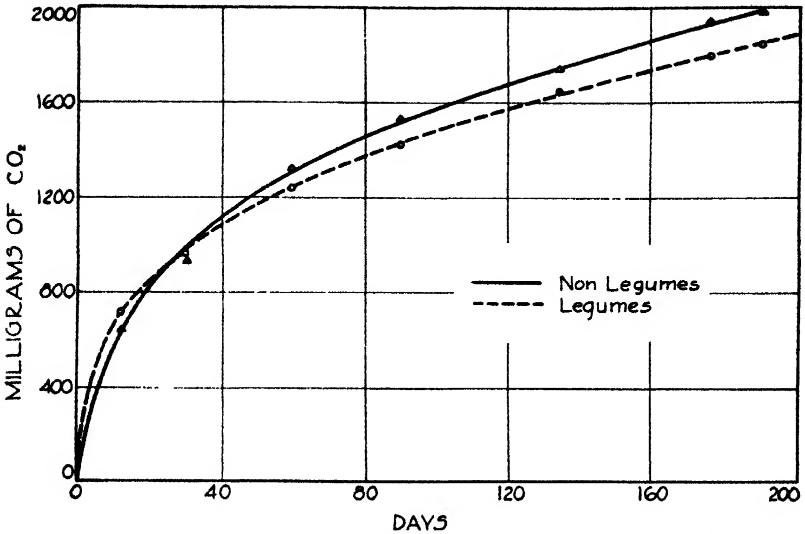

FIG. 2. Total mean CO_2 produced from four legumes and eight non-legumes.

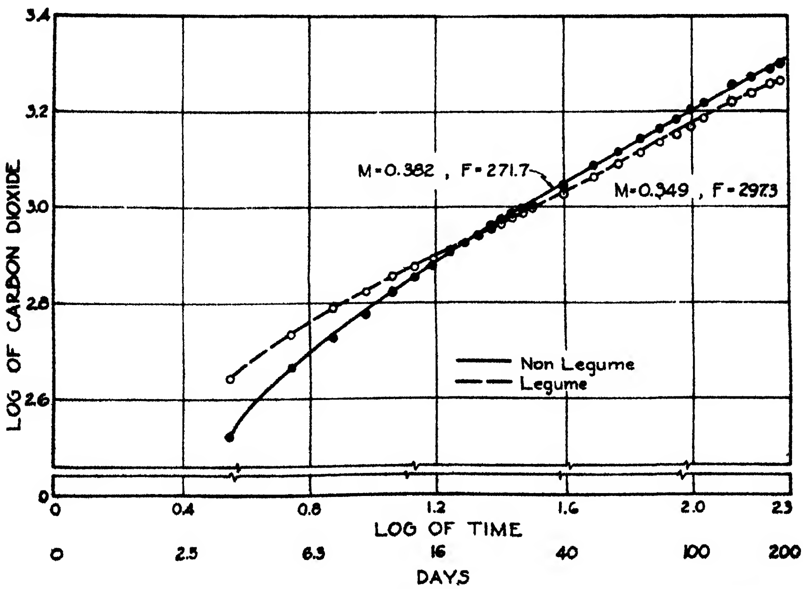

FIG. 3.—Total mean CO_2 produced from four legumes and eight non-legumes (milligrams).

clover evolved carbon dioxide at a higher rate than did any other soil during the first period, but for the third period, 9 to 26 days, the average daily production of carbon dioxide in this soil was at a lower rate than with any other treated soil. There was not a significant difference between the average daily rate of carbon dioxide production in all of the differently treated soils for any one period. However, there were groups of treatments differing significantly in the rate of carbon dioxide production during each period. During the first period the soil treated with alfalfa had the second highest daily rate of production of carbon dioxide. The differences in the average rate of production of carbon dioxide in the soils treated with red clover, soybeans, flax, and millet were not significant, but the group average differed significantly from that of the other treatments.

Hemp, cornstalks, cane sorghum, and sudan grass formed another group of treatments in the first period which differed significantly from the other treatments, but the differences between the members of the group were not significant. The rate of carbon dioxide production in the soils treated with wheat straw and oat straw did not differ significantly, but there was a significant difference between the average rate of production of carbon dioxide in these soils and those treated with any of the other materials.

Arranging the treatments into groups differing significantly in the average rate of carbon dioxide production and in decreasing order of the rate of carbon dioxide production, the following groups were obtained for the five periods.

Period I

Group 1. Sweet clover.
Group 2. Alfalfa.
Group 3. Red clover, soybeans, flax, and millet.
Group 4. Hemp, cornstalks, cane sorghum, and sudan grass.
Group 5. Wheat straw and oat straw.

Period II

Group 1. Oat straw, hemp, sudan grass, and flax.
Group 2. Wheat straw, cane sorghum*, cornstalks, millet, alfalfa, sweet clover, red clover, and soybeans.*

Period III

Group 1. Oat straw,† wheat straw, cornstalks, and hemp.
Group 2. Sudan grass, millet, and cane sorghum.†
Group 3. Flax and red clover.
Group 4. Alfalfa, sweet clover, and soybeans.

Period IV

Group 1. Hemp.
Group 2. Oat straw and wheat straw.
Group 3. Millet, cornstalks, cane sorghum, and sudan grass.

*Significantly different.
†Not significantly different.

Group 4. Flax and alfalfa.
Group 5. Red clover.
Group 6. Sweet clover and soybeans.

Period V

Group 1. Oat straw and millet.
Group 2. Wheat straw, cane sorghum, flax, hemp, and alfalfa.
Group 3. Sudan grass, cornstalks,* soybeans, red clover, and sweet clover.*

*Significantly different.

The amounts of carbon dioxide produced in the soils treated with the various plant materials after 228 hours listed in descending order were sweet clover, alfalfa, soybeans, flax, red clover, millet, hemp, sudan grass, cane sorghum, cornstalks, oat straw, and wheat straw.

The amounts of carbon dioxide evolved from the soils treated with eight non-legumes were averaged for comparison with the average amount produced in the soils treated with the four legumes and the untreated check. The data are given in Table 4 and Fig. 2.

An analysis of variance of the data showed a significant difference in the rate of decomposition of legumes and non-legumes. During the first period the leguminous materials decomposed more rapidly than the non-leguminous materials. During the second, third, and fourth periods, the non-leguminous materials decomposed more rapidly than the leguminous materials. After 121 days the rate of decomposition in the soils treated with the plant materials was not significantly different from the rate of decomposition in the check soil.

The logarithms of the total carbon dioxide evolved from the legumes and non-legumes were plotted against the logarithms of time and the results obtained are shown in Fig. 3. The curves show that during the first 2 weeks when most carbon dioxide was being evolved, the rate of carbon dioxide production was decreasing rapidly. However, after the initial period of rapidly decreasing rate of decomposition a linear relation existed between the amount of carbon dioxide evolved and the time until the end of the experiment. The m and F values were calculated from the equation $y = Ft^m$, where y represents the amount of carbon dioxide produced in time t and m and F are constants.

According to Corbet (2), the F value represents the amount of carbon dioxide produced in unit time at the beginning of the experiment and the m value is a measure of the retardation in the rate of carbon dioxide evolution during the phase of decrease. M may have any value less than unity. For the time period between 28 days and 175 days an m value of 0.349 was obtained for the legumes, and for the time period between 25 days and 175 days an m value of 0.382 was obtained for the non-legumes. This indicates that the rate of decomposition of the legumes was decreasing more rapidly than that of the non-legumes.

DISCUSSION OF RESULTS

The respiration chamber method for the determination of carbon dioxide production in soils was found to give slightly lower results in the beginning of the experiment than the aspiration method. The difference between the two methods with a given plant material was not large and was considered to be brought about by a stimulation of the activities of the micro-organisms caused by the aeration of the soil. The chamber method does not involve an aerating of the soil sample and is, therefore, considered to represent more nearly field soil conditions. The chamber method requires less time and less equipment for the determinations than the aspiration method and where the determinations are to be carried out over a long period the respiration chamber method might be preferred to the aspiration method. If, however, a short period of incubation is to be followed larger differences may be obtained by the aspiration method than by the respiration chamber method.

The respiration chamber method was found to give similar results when the chamber was stationary as when the chamber was rotated. An analysis of the air in the stationary chamber indicated no accumulation of carbon dioxide and an ample supply of oxygen.

The production of carbon dioxide in the soil was not found to be correlated with the carbon content of the plant materials added. The results obtained during the first few days of decomposition showed that the plant materials relatively high in nitrogen decomposed more rapidly than those with a relatively low nitrogen content. After this initial period the rate of decomposition of the materials low in nitrogen was more rapid than those of a relatively high nitrogen content.

These data indicate that when plant materials decompose in the soil a greater fixation of carbon results from materials containing a high nitrogen content than with materials of a low nitrogen content. This emphasizes the importance of having an ample supply of nitrogen present when an attempt is made to build up the humus content of the soil.

The data obtained in these experiments indicate a definite effect of kind of organic matter on the rate of decomposition under a given set of conditions. A change in any of the factors affecting the activity of the micro-organisms in the soil might be expected to alter the rate of decomposition. The reaction of the soil, the amount of moisture, the temperature, the aeration, and kind or species of micro-organisms are all important factors in the rate of decomposition of any organic matter in the soil. The same micro-organisms would probably give the same type of decomposition curve, that is, differing only in magnitude, under slightly different conditions of moisture, temperature, and aeration. However, different organisms may liberate different amounts of carbon dioxide and consequently show a different rate of decomposition of the same material. Therefore, the results obtained in these experiments are strictly applicable only to the Dickinson fine sandy loam, but the different kinds of organic matter probably affect the rate of decomposition more than the differences in the soil flora, especially when closely related types of soil are involved.

SUMMARY AND CONCLUSIONS

The rate of decomposition of 12 plant materials containing about the same amount of carbon but varying widely in percentage of nitrogen was determined by measuring the production of carbon dioxide in Dickinson fine sandy loam treated with the different materials. Preliminary studies were made on a comparison of two methods for determining carbon dioxide production in soils. The results obtained may be summarized as follows:

1. The aspiration method for measuring carbon dioxide production was found to give higher results than the respiration chamber method during the first part of the experiment, but after 624 hours the amounts of carbon dioxide evolved from the soils treated with the same kind of organic matter were about the same by both methods of determination.
2. The results obtained indicated that all of the carbon dioxide was being absorbed by the respiration chamber method.
3. The respiration chamber method was found to require less time and equipment than the aspiration method.
4. The plant materials high in nitrogen decomposed more rapidly during the first few days of decomposition than the plant materials low in nitrogen. After this initial period of decomposition the materials low in nitrogen decomposed more rapidly than the materials having a high nitrogen content.
5. The decomposition of plant materials high in nitrogen resulted in a greater fixation of carbon in the soil than the decomposition of materials with a low nitrogen content. This was evidenced by a decreased total carbon dioxide evolution from the soils treated with the plant materials containing a relatively high nitrogen content.

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THE USE OF ACTUAL AND COMPETITIVE YIELD DATA FROM SUGAR BEET EXPERIMENTS[1]

S. B. NUCKOLS[2]

IN reporting tonages of sugar beets produced in plat experiments, the total weight of all beets produced on the area without regard to stand is given as the actual yield, which is often contrasted with a calculated or theoretical yield obtained from "normally competitive" or "competitive" beets. The beets serving as the base for calculation are those which have grown surrounded by neighbors on all sides at appropriate distances for the condition imposed by the experiment. These properly spaced beets buffered by neighbors are assumed to have been grown under "normal competition" and their designation has often been shortened in use to "competitive" beets.

Since some experiments may be more accurately reported by one method than the other, it is important that critical consideration be given to the reliability of each as a basis for judgment in agronomic experiments. It is recognized that there will occur cases in which, because of stand variability, neither method can be employed. The ideal condition is a perfect stand on all plats under which conditions the actual yield and competitive yield should be identical.

Where the stand is not good it is not possible to know how much yield is lost by the missing beets, as the other plants usually make some utilization of the adjacent missing spaces. It is also true that where the stand is not good the truly competitive beets may be too few in number to give a basis for a correct calculated yield.

Securing of actual yield is the more commonly used method of obtaining data, although agronomists have generally eliminated portions of plats where obvious mishap would have invalidated reliable results. "Normally competitive beets" have been used as a basis for data because of the belief that these beets would avoid unmeasurable competition effects and give more reliable data than could be obtained in the absence of such selection. The purpose of this paper is to explore this assumption and to show that under certain conditions acceptance of the yield from competitive beets has resulted in increased error rather than a gain in reliability. The point of view held is not antagonistic to the truly "normally competitive" beet concept, but rather is a critical one based upon the belief that in field work such selections, with inadequate stands, perforce cannot be properly restricted. Some of the difficulties encountered in obtaining actual and competitive yields in various types of sugar beet experiments are mentioned for the purpose of inviting further discussion of this problem, because at present there exists some confusion in the interpretation of the practical application of the results from a portion of the experimental sugar beet work.

[1]Contribution from the Division of Sugar Plant Investigations, Bureau of Plant industry, U. S. Dept. of Agriculture. Received for publication August 8, 1936.

[2]Associate Agronomist. The author wishes to express his appreciation to Dr. T. A. Kiesselbach of the University of Nebraska and to E. S. Lyons of the Division of Soil Fertility Investigations and G. H. Coons of the Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, for many helpful suggestions in the presentation of these data.

USE OF COMPETITIVE PLANTS IN YIELD DETERMINATION

The background for the use of competitive plants to obtain yields of sugar beets can be gained from the literature of similar work on other crops.

In 1918, Kiesselbach (4)[3] published a paper on experimental errors in crop tests in which he described a method of selecting hills of corn which were completely surrounded by adjacent hills and from these a calculated yield was obtained for a theoretical 100% stand. Kiesselbach's method has been generally adopted by experimentors in growing corn in hills 3½ feet apart. The root growth of corn is generally confined to the area between the hills, since corn roots are from 3 to 4 feet in length. Kiesselbach (5) has been a leader in the studies of stand effects upon yields and in 1923 published a paper on competition as a source of error in comparative corn yields. Kiesselbach and Weihing (6) in 1933 concluded that individual corn plants were more capable of variation than total yield under practically normal conditions.

Stewart (10, 11) reports work on missing hills in potato fields whereby he finds that hills adjacent to missing spaces in part utilize the additional area.

In 1930, Werner and Kiesselbach (12) published upon the effect of vacant hills in potato fields planted at 15-inch intervals in rows. They calculated the competitive yield from plants three to four hills distant from the vacant hills.

In 1926, Sprague and Farris (9) published work on the effect of stand on the growth of barley in which they concluded that selection of individual plants was not possible, due to the fact that the roots of the plants were in no manner confined to the same area as the top growth.

Andrews (1), in 1927, published data upon the growth of sugar beet roots, in which he concluded that sugar beet roots spread approximately 3 feet in all directions from the beet plant.

The literature cited seems to indicate that investigators of the effect of missing spaces on yields of corn and potatoes find conditions suitable to the selection of competitive plants and are thereby able to make corrections for missing spaces. On the other hand, it is found impractical to select competitive barley plants. As root growth may bear an important part in the discussion, a citation is made of root growth of sugar beets. If different crops respond differently when the selection of competitive plants is attempted, what are the limitations which must be imposed upon the selection of competitive sugar beets?

The practice of selecting "normally competitive" beets from plats to secure data has been frequently employed in agronomic work in the Division of Sugar Plant Investigations. Wherever data have been obtained in this way, the type of selection employed has been given and results expressed on the basis of 100% stand of such beets. It is not known who originated the method, and so far as the writer knows, test of its adequacy in reducing or eliminating competition effects has not been reported.

In Fig. 1 is given an illustration of the beets which are selected or discarded in obtaining competitive beets. The writer has followed this practice in the work reported in this paper and the same practice has, in general, been followed by the agronomists in the Division of Sugar Plant Investigations. Such variations as have occurred in in-

dividual experiments have been reported. This method discards only one beet on each side of a vacant space in the row and three beets in each of the adjacent rows. Beets are normally grown in rows 20 inches apart and spaced 12 inches apart in the row. However, variations in distances between beets in the row are used in spacing tests and competitive beets from such tests must coincide with their respective spacing requirements.

X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	X
X	X′	X′	X′	X′	X′	X′	$\underline{X}$	X′	X′	X′	X′	$\underline{X}$	X
X	X′	O	X′	X′	O	X′	$\underline{X}$	X′	O	O	X′	$\underline{X}$	X
X	X′	X′	X′	X′	O	X′	$\underline{X}$	X′	O	O	X′	$\underline{X}$	X
X	$\underline{X}$	$\underline{X}$	$\underline{X}$	X′	X′	X′	$\underline{X}$	X′	X′	X′	X′	$\underline{X}$	X
X	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	$\underline{X}$	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X

FIG. 1.—Diagram of plan used in harvesting competitive beets.

O = Missing hill; X = Border beets not used; $\underline{X}$ = Competitive properly spaced beets; and X′ = Beets adjacent to missing spaces and discarded.

TREATMENTS AFFECTING THE STAND

There are certain treatments which occasionally have a definite influence upon the stand. Under such conditions it is not possible to determine that the differences in stand are entirely due to treatment; however, in carefully planned work, it should be possible to determine whether the differences in stand were due to treatment or to outside influences.

Where stand is injured by outside influences, it is obvious that some allowance must be made for the lost area. On the other hand, if the treatment injures the germination of the seed, destroys part of the plants, or in any manner is directly responsible for the stand, the competitive beets from the remaining stands do eliminate the effect of the treatment in those instances in which the beets were killed. The killing effect of the treatment is a definite part of the results obtainable and should be given consideration.

In a spacing experiment the plants are left at definite intervals and in the close spacing more plants are left than in the more distant spacing. In such experiments there has been some discussion as to what is the desired finding. One finding is to determine what is the average yield and average size of beet where the plants are spaced 12 inches apart in 20-inch rows and determine what the yield would be provided all spaces were filled at the desired interval. The other finding is to take the average field under average conditions for the area and determine what 12-inch spacing will produce at harvest time in regard to perfection of stand and the actual yield. This latter

method assumes that there will normally be certain climatic and seasonal hazards which will deplete a portion of the stand and has a decided practical application.

SELECTION OF COMPETITIVE BEETS FROM AN UNEQUAL STAND HAVING THE SAME SPACING INTERVAL

The usual spacing of sugar beets is 12 inches between beets in the row with the rows 20 inches apart. Absolute uniformity of stand or equality of stand is not common. The present discussion is entirely limited to those variations in stand which are due to other causes than the treatment, as the handling of experiments where stand is influenced by treatment is discussed in a previous paragraph. There are several possible methods of handling experiments which have wide variations in percentage of stand. Some have reported actual yields from experiments regardless of stand; others have selected competitive beets and reported a theoretical or calculated yield; while in some instances attempts have been made to make a correction by use of the average weight of beet of the actual yield and considering the variations in percentage of stand.

It is obvious that the last-mentioned method would involve many unknown factors and numerous calculations and often fail to supply a definite basis warranting the calculations. As an illustration of an extreme condition which will be encountered in attempting to determine the effect of area or percentage stand upon the average size of beet, attention is called to a publication by the author (7) where it is shown that in 1925 the size of beet varied from 1.58 pounds per beet where 30,000 beets were grown per acre to an average weight of 2.85 pounds per beet where only 7,000 beets were grown per acre. This is a distinct response of the beet to increased area. The following year, in the same area, curly-top severely injured the beets and with the same variations in stand of beets the average size of beet ranged only from 0.98 pound to 1.06 pounds, respectively. This is admitted to be an extreme condition, however Brewbaker and Deming (3) give the results from four fields in which they studied the effect of missing spaces upon the adjacent beets. Their fields are more normal and relatively uniform in the response of the beet to additional space and indicate a greater possibility of correction for missing spaces in normal fields. In their work, with one blank space in an adjacent row, the difference in effect varies from 105.4% to 130.9%, which is ample difference in variation in response of beet to increased space to indicate that data obtained over a number of fields or seasons cannot be used in the correction of an individual plat. Whenever a calculation is made for correction of stand, it probably should be very closely based upon the data taken from the individual plat.

It has been previously stated that the present standard for competitive beets as used by the U. S. Dept. of Agriculture discarded only those beets adjacent to a missing space. Fig. 2 gives some results from 254 plats in which there was a variation from a 50% stand to a perfect stand of 100%. These data are grouped in variations of 10% of stand with a mean calculated for each group. On these plats both the actual and competitive yield were harvested.

It is found that as the stand decreases the average size of beet increases in both those taken for competitive yield and those taken for actual yield. The result is that the actual yield in part compensates for loss of stand by utilization of missing spaces by the remaining beets. Assuming this extra size of beet is due to additional space, it should have been corrected by the selection of the competitive beets; however, these data indicate that the correction was

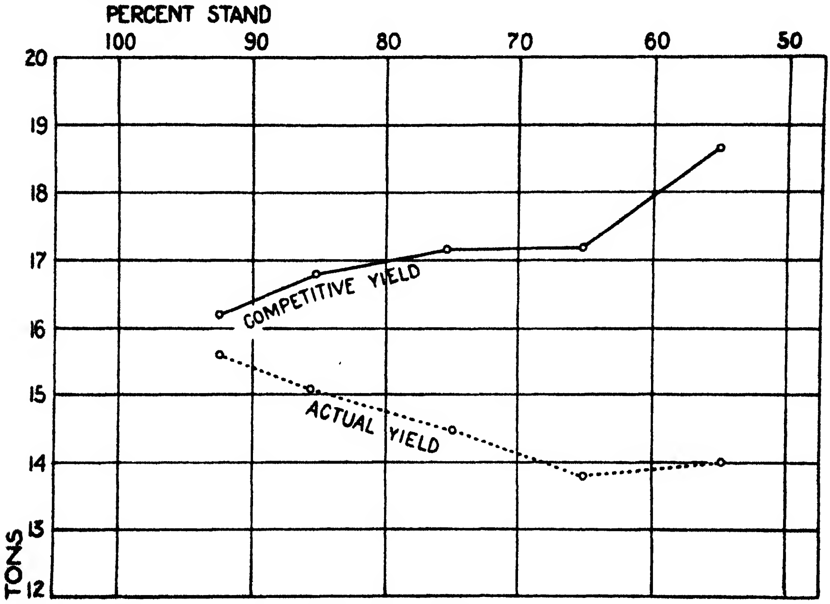

FIG. 2.—Actual and competitive yield of beets from 245 plats spaced 12 inches between beets in the rows. Plats are grouped and averaged for percentage stand at harvest time. The data are from seven experimental fields, not spacing tests.

incomplete. The curves trend in opposite directions, and the competitive yield, rather than correcting the error, increases the error in an opposite direction. The normal assumption is that the competitive beets should have corrected these randomized plats so that the competitive yield was approximately identical for all plats. In this case neither the actual yield nor the competitive yield appear to be accurate; however, the actual yield is logical and what is normally expected.

The above is an indication for either more restriction upon the selection of competitive beets or the abandonment of plats where the variation in stand is great.

Robbins and Price (8) give data (Table 6) showing actual and competitive yield from two fields in which they have four comparisons of actual and theoretical yield of beets with the variation in size of beet in one instance 0.01 pound per beet difference in weight between the average size of actual yield beets and the average size of competitive beets. In the other three instances the variation is 0.0[illegible]

pound per beet between the average size of actual beets and competitive beets. In field A the average size of actual beet was greatest on the plats having the poorer stand, while in field B the average size of beet was greatest on the plats with the most dense stand. In all cases, if the authors had used the average size of actual beet instead of competitive beet, they would have obtained within 2% the same yield per acre as they did from their competitive beets. The data in their Table 6 do not show clear evidence that increased area had an effect upon size of beets, while in Table 7 of the same publication they show a definite response of beets to area.

It does not seem that under normal conditions the average size of actual beet and average size of competitive beet are the same, as the beet normally responds to additional space. However, Robbins and Price describe the competitive beet as follows: "By a normally-competitive beet is meant one which is 20 inches distant from a neighbor on two sides and 12 on the other two." This would indicate that only four beets around the missing space were discarded, whereas the practice diagramed in Fig. 1 discards eight beets surrounding a missing space. Insufficient data have been presented in this paper for the determination of the actual causes of the increased yields which were obtained from the use of competitive beets from poor stands; however, it seems probable that beets obtaining benefit from missing spaces have been included in the competitive beets selected from poor stands.

MATHEMATICAL POSSIBILITY OF SELECTION OF COMPETITIVE BEETS FROM PLATS WITH POOR STANDS

Blank spaces in sugar beet fields are of two types, First, those which are distributed over the field in which usually only from one to three beets in a place are missing. These are by far the most common, as they are caused by such factors as horse tracks, too deep covering, unequal germination of seed, careless thinning, insect injury, hail injury, and other factors which are generally distributed over the field. The second type of blank space consists of larger areas, usually involving two or more rows. These are less prevalent in experimental plats but are often found in commercial fields and are caused by faulty cultivation or wind and water damage.

Where large areas are involved it is possible to take either the actual yield from the better part of the plat, thereby reducing the size of the plat, or to select competitive beets from the same part of the plat that the actual yield had been obtained.

If missing spaces are distributed at random over the plat and occur, as they most often do, with from one to three missing spaces in a place, it does not require very many missing spaces to eliminate the possibility of selection of competitive beets. Too often in selection of competitive beets the number obtainable is insufficient for correct yield determination.

The mathematical possibility of selection of competitive beets from different percentages of stand is that from a 90% stand there are about 35% of the beets which are competitive with 20% of these being only one beet removed from a missing space. From an 80%

stand about 10% of the beets are competitively grown and 40% of these are from beets grown only one beet removed from a missing space. From a 70% stand about 5% of the beets are competitive and approximately 70% of these are grown only one beet removed from a missing space. This indicates the greater possibility of error from competitive beets taken from poor stands. The above calculations are made under the standard set up shown in Fig. 1 wherein it is required that eight beets be discarded adjacent to a single missing space.

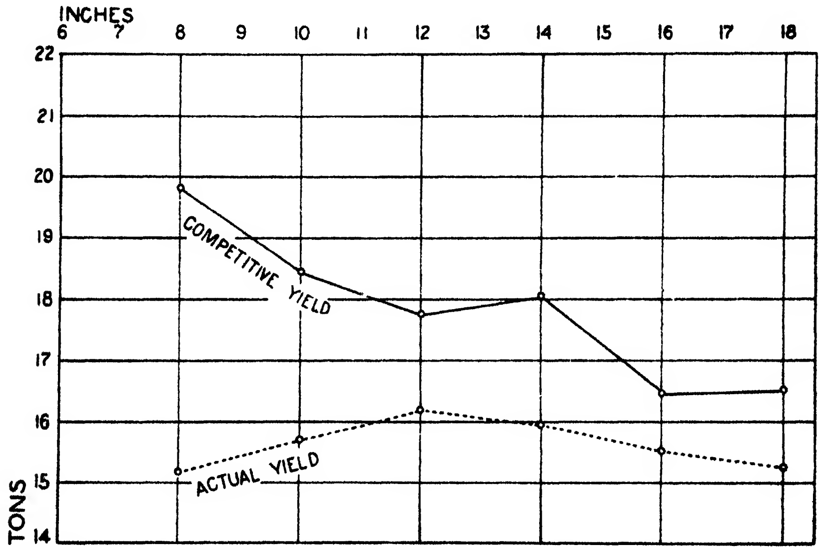

FIG. 3.—Competitive and actual yields from sugar beet spacing tests.

ACTUAL YIELDS AND COMPETITIVE YIELDS FOR SPACING EXPERIMENTS

In spacing experiments there are some factors which come into the discussion of reliability of the use of competitive beets which are not involved in plats where the same interval of spacing is used for the different treatments. The first of these is the fact that the second beet in the row from a missing space is much closer to the missing space where the spacing is 6 inches than it is when the spacing is 18 or 24 inches in the row. The second factor is that there are normally fewer missing spaces in widely spaced beets than in closly spaced beets. It may be said that the blank portions are smaller in the case of closely spaced beets, therefore this would compensate for the fact that the beets were more favorably situated in regard to the missing space. This matter cannot be accurately determined without some very carefully planned and well conducted experiments for this particular problem.

Fig. 3 gives the results from 12 fields in which the actual yields and competitive yields were harvested from spacing experiments. Each of

these fields had five or six replications of each treatment. The plats have been from 4 to 16 rows wide and from 50 to 150 feet in length. These data are very conflicting in that the actual yield on the plats indicates that the highest tonnage is obtainable from 12-inch spaces, while the 18-inch spacing is lower than the 12-inch spacing but is not so low as the 8-inch spacing. On the other hand, the competitive beet yields are highest from the 8-inch spaced plats with the wider-spaced plats producing lower yields.

One of the important problems is whether similar yields have been obtained by other investigators using competitive beets in reporting spacing experiments. For this purpose Fig. 4 is presented giving the competitive yields from the 12 fields presented in Fig. 3 with the competitive yield as presented by Robbins and Price (8) in their Table 7 and the data from a large number of fields presented by Brewbaker (2). These published data indicate that similar results have been obtained in three widely scattered areas as the highest yield from competitive beets was obtained in closer spacing in all three instances.

Fig. 5 is introduced to show the difference the writer has obtained in the harvesting of competitive sugar beets from fields of different percentages of stand. The lines C 1 and C 2 are the same as the ones shown in Fig. 4. As the data in C 1 are made up from 12 different fields, the 12 fields are divided on the basis of the percentage of stand in the 12-inch spacing. The six fields with the better stand had an 89% stand in the 12-inch spaced plats and are shown in line C 3, and the six fields with the poor stand had an average stand of 64% in the 12-inch spaced plats and are shown in line C 4. These indicate that from the closely spaced plats a very high yield was obtained, while from the widely spaced plats a much lower yield was obtained where the stand was sparse, but it indicates that a very similar yield was obtained from all types of spacing where the stand was more dense. The two divisions produced approximately the same yield from the 12-inch spacings. The variation in data obtained is an indication of some weakness in the method. The competitive beets from the better stands would perhaps be considered the more accurate.

The line AC 5 is included in Fig. 5 and is the actual yield from a field where the stand was 98% perfect. The competitive beets were not dug from this plat. The common assumption would be that the competitive beets from a 98% stand would practically be the same as that for the actual yield; however, the writer knows of no occasion where competitive beets have been dug from spacing plats with perfect stands.

The method used for harvesting competitive beets in spacing experiments has been the same as that illustrated in Fig. 1. The effect of the method is not the same for all treatments when the space between beets in the row is varied. The result is that in a 6-inch spaced plat some beets have been selected within 12 inches of the missing place; in 12-inch spacing some beets have been selected within 24 inches of the missing places; in the 18-inch spacing no beets have been selected less than 36 inches from the missing place; while for 24-inch spacing the limit for selection is 48 inches. This has permitted the selection of one beet in the first 48 inches of row adjacent

to a missing place in 18-inch or 24-inch spacing; while three beets have been selected from the same area in a plat spaced 12 inches and as many as seven have been selected from the same area in a plat

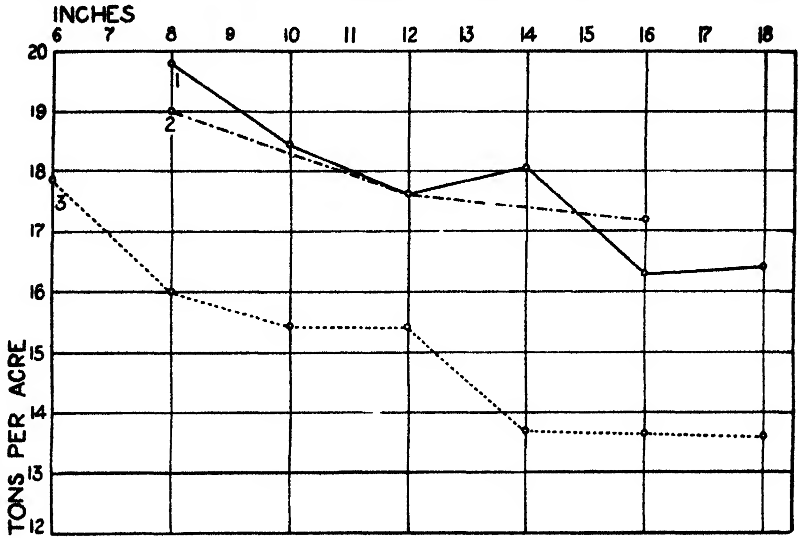

FIG. 4.—Competitive yield of sugar beet spacing tests by three investigators. 1, Nuckols (Fig. 3); 2, Brewbaker (2), and 3, Robbins and Price (8).

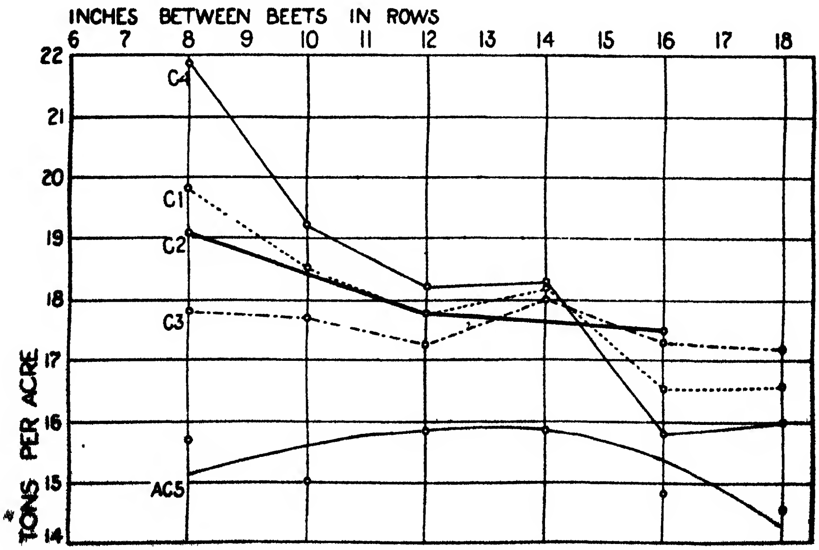

FIG. 5.—Competitive yields of sugar beets from variable stands. C4, 64% stand in 12-inch spaced plats; C1, means of C4 and C3; C2, from 16 fields, Fort Collins, Colo.; C3, 89% stand in 12-inch spaced plats; and AC5, actual and competitive yield form 98% stand.

spaced 6 inches. To select competitive beets in a spacing experiment, it is probable that for absolute equality beets should be selected only at a distance of twice the greatest spacing interval.

There is a possibility that a slight error may occur in some instances in determination of the space in which the competitive beet grew, i. e., if a 7-inch beet is obtained where the desired interval is 6 inches, the error is 1/6, or 16 2/3%, while if a 19-inch beet is selected for a desired 18-inch beet, the error is 1/18, or 5.6%.

The writer is searching for an explanation of the reasons for the difference between the actual and competitive yield being greater in the closely spaced plats than in the widely spaced plats.

When this sort of disagreement occurs in data, the cause of the occurrence is necessary before a conclusion can be made regarding the correctness of either method.

The writer does not endorse either the actual or competitive method of reporting sugar beet yields. There are instances where the actual yield should be reported and other instances where the competitive yield seems to be preferred.

This paper is primarily a criticism of the present methods of selecting competitive sugar beets in that in some instances apparently fully competitive beets are not obtained.

SUMMARY

When competitive sugar beets are selected by the standard outlined in Fig. 1, it has been found that there are greater differences between competitive and actual yield where the stands were poor than where the stands were good. There is also indication that there is a greater difference between competitive and actual yield where the beets were closely spaced than where they were more widely spaced in the row.

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CHANGES IN THE PROPORTIONS OF THE COMPONENTS OF SEEDED AND HARVESTED CEREAL MIXTURES IN ABNORMAL SEASONS[1]

K. H. W. KLAGES[2]

THE presence of mixtures in cereals and other crop seeds constitutes a problem not only to plant breeders, producers of "pure seeds", but also to commercial interests. These admixtures become troublesome especially when composed of closely related crops belonging to two or more market classes. Thus, a high percentage of the durum wheat seed used in the Great Plains area contains varying admixtures of hard red spring wheat. Admixtures of durum in hard red spring wheats are also common.

Under ordinary conditions of culture it is generally considered that the respective productive capacity of each of the components making up a mixture determines the differences between the relative proportions of the admixtures seeded and harvested. In this connection the capacities of production for such components must, however, be regarded in the light of a competitive capacity. A given plant forced into close competition with plants of differing growing habits may react quite differently than one competing with plants of its own kind. Great differences in the comparative producing capacities of components of mixtures may, of course, be expected in those particular seasons with environmental factors favorable, or in certain instances less detrimental, to one of the components than to another. Thus, the proportion of rye in a winter wheat-rye mixture will increase materially under conditions unfavorable to the winter survival of the wheat but not especially detrimental to the rye. Components of a mixture may either increase or decrease as environmental conditions may either favor or hinder them in their struggle with competing plants.

The experimental results to be reported were obtained at the South Dakota Agricultural Experiment Station at Brookings during the season of 1935. The particular growing conditions of the season of 1935 had much to do with the results obtained. Moisture and temperature relations were favorable to a heavy vegetative growth, especially during the early portion of the season. This led to a very succulent type of growth and the development of an exceptionally large number of tillers. By the first week of July one of the severest stem rust epidemics on record in the northern Great Plains area developed and progressed rapidly. Climatic conditions and the type of growth produced during the earlier part of the season were ideal for the development of stem rust. Consequently, all varieties of wheat, with the exception of certain special resistant varieties and selections, were severely damaged.

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[1]Contribution from the Department of Agronomy, South Dakota Agricultural Experiment Station, Brookings, S. D. Also presented at the twentieth annual meeting of the Western Branch of the Society held at Pullman, Wash., and Moscow, Idaho, June 22–24, 1936. Received for publication August 11, 1936.

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MATERIALS AND METHODS

Mixtures of three varieties of hard red spring wheat, Marquis, Ceres, and Reward, with durum wheat, Mindum, were compounded in proportions as indicated in Table 1. Like mixtures were also employed in the oats and barley studies. Richland oats and Odessa barley were used. The mixtures were made up so as to give ranges from pure stands of the two respective varieties or crops used and small and large combinations of each class. All percentage determinations were based on weight.

These mixtures were planted in triplicate rows 18 feet long, at the rate of 12 grams of seed per row, and repeated three times. Before harvest the rows were trimmed to a length of 1 rod. Threshing was performed with a standard nursery thresher. Percentage determinations of the threshed grain were made after the removal of foreign material.

YIELDS OF HARD RED SPRING AND DURUM WHEAT MIXTURES

Table 1 gives the yields of the various combinations of durum with the three varieties of hard red spring wheat used.

It will be observed that the yields of the various combinations decreased in all instances as the proportions of hard red spring wheat in the admixture increased. The differentials in the yields of the various varieties in pure stands and in the mixtures are very interesting. They stand in direct relation to the specific reaction of the respective varieties to the stem rust epidemic. All three varieties of hard red spring wheat showed themselves as very susceptible. Marquis and Reward were known from past performances to be very susceptible. Ceres has a certain degree of resistance to stem rust and has produced good yields in years with mild epidemics. Under the conditions of the severe epidemic of 1935 it showed towards maturity practically as high an infection as Marquis; rust developed, however, somewhat slower on Ceres than on Marquis. This accounts for the higher yields of Ceres as compared with those obtained from Marquis. The comparatively high yields of Reward are accounted for by its earliness. It was more advanced than the other varieties at the time the epidemic became severe. Five days prior to maturity the three varieties showed between 80 and 90% of stem rust. Mindum, as its low yields indicate, was also severely affected by the rust epidemic, showing around 60% of rust at maturity. Rust developed less rapidly on the durum than on the hard red spring wheat varieties. It is evident that the results reported in Table 1 would have been even more outstanding than they are if a stem rust resistant variety of durum, such as Pentad or Acme, had been used in these trials in place of Mindum, a susceptible variety.

COMPOSITION OF HARVESTED CROP OF HARD RED SPRING WHEAT AND DURUM WHEAT MIXTURES

Table 1 gives the percentage contents of durum and hard red spring wheats in the harvested crop of the given mixtures. The last column of Table 1 shows the excess of durum in the harvested crop over the percentage seeded. Fig. 1 gives a graphic presentation of the differences in composition of the seeded and harvested crop. The durum

components, as would be expected from the comparative yields reported, show significant increases in all of the varietal mixtures. Furthermore, these increases of the durum components in mixtures with the three respective varieties of hard red spring wheat used stand in direct relationship to the comparative yields of these varieties. Marquis was lowest in yield. The increase of durum in the Min-

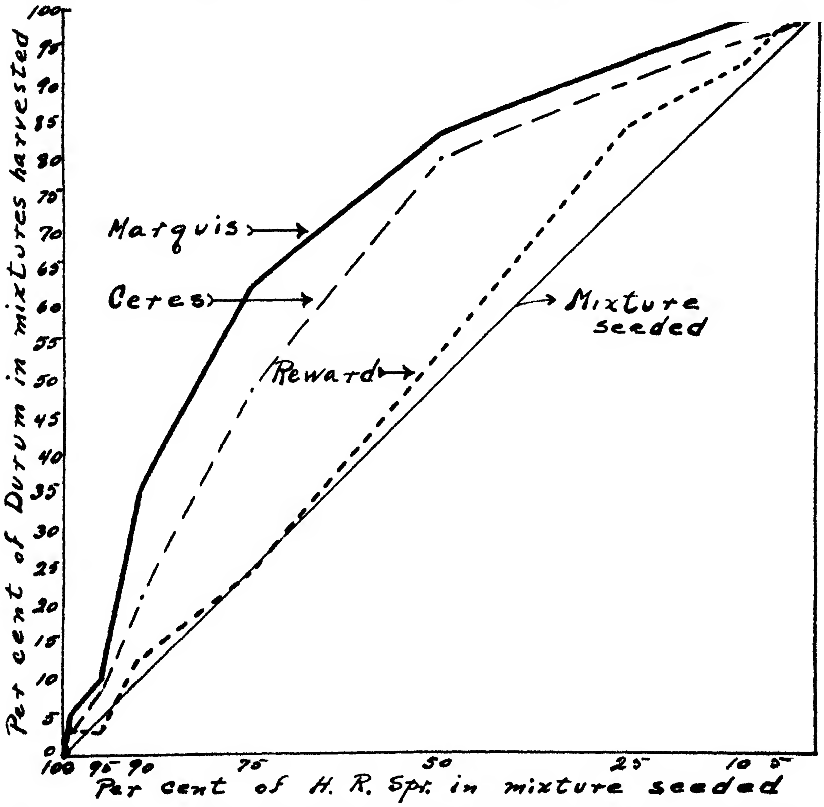

FIG. 1.—Percentages of durum in seeded and harvested crops of Mindum-Marquis, Mindum-Ceres, and Mindum-Reward mixtures.

dum-Marquis mixtures was exceptionally high. Ceres in pure stands yielded significantly higher than Marquis; however the percentage of durum harvested from the Mindum-Ceres mixtures was high though lower than in the Mindum-Marquis mixtures. The Mindum-Reward mixtures exhibited increases in durum components in most instances, the increases, however, being much lower than in the cases of the two first-mentioned mixtures. The increases of the durum components in these various mixtures stand in direct relationship to the stem rust reactions of the respective varieties of hard red spring wheat used.

YIELDS OF OATS AND BARLEY MIXTURES

Table 2 gives the yields of oats and barley mixtures compounded in the same proportions as the wheat mixtures previously discussed. It

TABLE 1.—*Changes in the proportions of components of seeded and harvested mixtures of hard red spring and durum wheats.*

Mixture seeded, % by weight		Yield in bushels per acre	Composition of harvested crop		Excess of durum in harvested crop over percentage seeded
Durum %	Hard red spring %		Durum, %	Hard red spring %	
		Mindum-Marquis			
100	0	14.8	100.00	0.00	0.00
99	1	13.4	99.99	0.01	0.99
95	5	12.1	99.44	0.56	4.44
90	10	12.4	98.16	1.84	8.16
75	25	11.4	93.09	6.91	18.09
50	50	8.7	83.73	16.27	33.73
25	75	5.5	63.64	36.36	38.64
10	90	4.8	35.63	64.37	25.63
5	95	4.7	10.34	89.66	5.34
1	99	3.2	5.39	94.61	4.39
0	100	3.4	0.00	100.00	0.00
		Mindum-Ceres			
100	0	14.8	100.00	0.00	0.00
99	1	13.6	99.43	0.57	0.43
95	5	11.8	97.49	2.51	2.49
90	10	11.2	96.20	3.80	6.20
75	25	11.6	91.28	8.72	16.28
50	50	10.5	80.23	19.77	30.23
25	75	9.5	48.30	51.70	23.30
10	90	7.5	21.55	78.45	11.55
5	95	6.6	8.09	91.91	3.09
1	99	5.7	2.45	97.55	1.45
0	100	6.5	0.00	100.00	0.00
		Mindum-Reward			
100	0	14.8	100.00	0.00	0.00
99	1	13.4	98.50	1.50	−0.50
95	5	12.3	97.55	2.45	2.55
90	10	12.8	93.00	7.00	3.00
75	25	11.6	84.60	15.40	9.60
50	50	12.0	53.45	46.55	3.45
25	75	11.3	24.24	75.76	−0.76
10	90	11.2	12.40	87.60	2.40
5	95	10.0	3.10	96.90	−1.90
1	99	11.2	3.35	96.65	2.35
0	100	10.8	0.00	100.00	0.00

will be observed that the yields of the various combinations of these two crops did not differ greatly. Richland oats and Odessa barley were used in these mixtures. Richland is a low-growing, early-maturing, stem rust-resistant variety. Odessa is a fairly rank-growing Manchuria type of barley. No stem rust developed on the Richland oats. The Odessa barley showed around 30% of rust at maturity; the rust, however, developed late enough in the season so that it did not greatly interfere with grain production.

TABLE 2.—*Changes in the proportions of components of seeded and harvested mixtures of Richland oats and Odessa barley.*

Mixture seeded, % by weight		Yield in grams per rod row	Composition of harvested crop		Excess of barley in harvested crop over percentage seeded
Richland oats	Odessa barley		Oats %	Barley %	
100	0	333	100.0	0.0	0.0
99	1	320	93.6	6.4	5.4
95	5	323	82.8	17.2	12.2
90	10	301	84.8	15.2	5.2
75	25	357	47.5	52.5	27.5
50	50	327	23.1	76.9	26.9
25	75	320	8.1	91.9	16.9
10	90	322	2.3	97.7	7.7
5	95	320	1.0	99.0	4.0
1	99	302	0.2	99.8	0.8
0	100	300	0.0	100.0	0.0

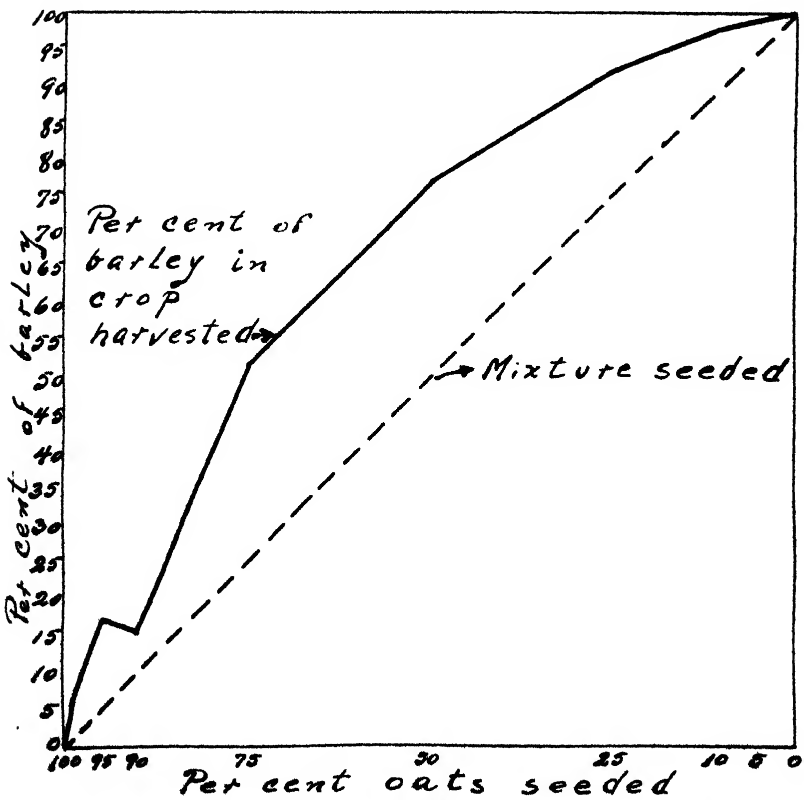

FIG. 2.—Percentage of barley in seeded and harvested crops of oats and barley mixtures.

COMPOSITION OF HARVESTED CROP OF OATS AND BARLEY MIXTURES

Table 2 gives the percentage contents of oats and barley in the harvested crops of the given mixtures. The last column of the table shows the excess of barley in the harvested crop over the percentage seeded. Fig. 2 gives a graphic presentation of these differences. A significant increase in the barley component is in evidence for all of the combinations planted. This may be accounted for by the differences in the growth habits of these two respective crops and by the fact that the early part of the season favored an extremely heavy vegetative growth. The barley was able to utilize the conditions favorable to early stooling and vegetative development to a greater degree than the less rapidly growing oat plants and was consequently able to crowd out some of the oat plants. The fact that the yields of the two respective crops when grown in pure or nearly pure stands did not differ materially rather serves to substantiate this theory.

SUMMARY

Exceptionally large increases in the durum components of durum-hard red spring wheat mixtures were observed. Likewise, the barley components of various combinations of oats and barley increased materially over the percentage of barley planted.

These larger-than-to-be-expected changes in mixture components were explained by the particular growing conditions and by the occurrence of one of the most severe stem rust epidemics on record in the northern portion of the Great Plains area.

TIMOTHY SELECTION FOR IMPROVEMENT IN QUALITY OF HAY[1]

MORGAN W. EVANS AND J. E. ELY[2]

SOME timothy plants, as they approach maturity, tend to preserve the normal green color of their leaves longer than others. This tendency, observed in the course of timothy breeding at North Ridgeville, Ohio, through a period of several years,[3] has been used as the basis of further selection aimed at improvement in the quality of hay. To determine the relation between the number of late-maturing leaves and the quality of hay, a special study was made in 1935. The factors considered in measuring quality were color of leaves, commercial grade, and protein content of the hay.

MATERIALS AND METHODS

The strains studied included ordinary unimproved timothy which blooms and matures at a medium date; one early selection, F. C. 11901;[4] and one late selection, F. C. 15167. The two selected strains represent three generations of continuous selection for either earliness or lateness and for the tendency for the leaves to remain green.

Late in April, 1935, 20 shoots, all of approximately the same size and age, of each strain of timothy studied were selected for observation from broadcast plats which had been sown in September, 1933. The 20 snoots of each strain were distributed in triplicate plats--7 in each of two plats and 6 in the third plat. Since a small portion of the stems became broken, records of less than 20 shoots of each strain were completed.

Observations were made at intervals of 2 or 3 days from April 18 until the growth of each shoot was completed, with the exception that, due to unfavorable weather conditions, no records were obtained from June 14 to June 20. A record was made of the date the tip of each leaf blade appeared, when the blade had fully emerged and unfolded, when the blade began to dry at its tip, and when it had finally become entirely dry.

At frequent intervals composite samples from each one of the triplicate plats were collected and cured in a building where they were protected from sun, rain, and dew. Each sample later was analyzed for nitrogen, and the percentage of protein calculated by multiplying by 6.25. On eight dates other composite samples were also collected, cured in a similar manner, and used for determining the color reading or hue, the percentage of green color, and the U. S. grades of hay which they represented.

[1]The data in this report were obtained at the Timothy Breeding Station, North Ridgeville, Ohio, conducted cooperatively by the Division of Forage Crops, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Ohio Experiment Station, Wooster, Ohio. Received for publication August 11, 1936.

[2]Associate Agronomist and Agent, respectively, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]EVANS, M. W. Selection of open-pollinated timothy. Jour. Amer. Soc. Agron., 28:389–394. 1936.

[4]Accession number of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.

RESULTS

EARLINESS OR LATENESS AS INDICATED BY TIME OF BLOOMING

Estimates were made daily, except when, because of unfavorable weather conditions, no florets bloomed, of the percentages of heads in full bloom in the plats of each strain used in this investigation. A timothy head was considered to be in full bloom during the time when its florets were in bloom throughout two-thirds or more of its entire length.[5] Each plat was recorded in full bloom on each date when 50% or more of the heads in it were in full bloom.

The early selection, 11901, was in full bloom from June 26 to 30, inclusive; ordinary timothy from June 30 to July 7; and the late selection, 15167, from July 5 to 11.

THE GROWING HABITS OF TIMOTHY LEAVES

The records in this report refer to the five uppermost leaves on the culm of each shoot In an earlier study of the life history of timothy, it was found that there were an average total number of 4 9 elongated internodes in the culm -above the "bulb" or haplocorm at its base In both the haplocorm and culm there were 6 1 internodes [6]

In the investigation reported in this paper, the average numbers of elongated internodes in the haplocorm and culm on the shoots of the various strains were 6 6 for 11901, 6.6 for ordinary timothy, 6.4 for 15167. Since there is a leaf immediately below each internode, the five leaves studied on each shoot represent fairly well those on the elongated culm, above the haplocorm. These five leaves include practically all which would be collected in harvesting timothy for hay.

Table 1 shows that, in general, the earlier the florets of any strain of timothy bloom, the earlier the leaves of the culms make their appearance.

TABLE 1.—*Average date on which the tips appeared on each one of the upper five leaves of the culms of each strain of timothy*

Strain	Average date of emergence of tip of leaf*					
	5	4	3	2	1	Average
Early, 11901	Apr. 26.3	May 4.2	May 13.3	May 24 0	May 31.3	May 13.8
Medium, ordinary	Apr. 29.2	May 6 2	May 16.1	May 26 3	June 3.7	May 16.5
Late, 15167	May 3.0	May 11.0	May 21.7	May 30.7	June 9.3	May 21.3

*Leaf 1 is next to the head, leaf 2 the second below the head, etc

INTERVALS BETWEEN THE APPEARANCE OF DIFFERENT LEAVES

Table 2 shows the average time required for each one of the upper five leaves on shoots of ordinary timothy to emerge, the time during which they remained entirely green, the time required for the blade to dry, and the total number of days elapsing from the time the tip of the leaf first appeared until its blade finally became dry.

[5]EVANS, M. W. Some methods of recording data in timothy breeding. Jour. Amer. Soc. Agron., 14:62-69. 1922.

[6]EVANS, M. W. The life history of timothy. U. S. D. A. Bul. 1450. 1927.

TABLE 2.—*Average number of days on the shoots of ordinary timothy for the leaf blades to emerge, remain green, and to become dry:*

Leaf No.*	Average number of days			
	From time tip appeared until blade had entirely emerged	From time blade had full emerged until drying began at tip	Required for complete drying of leaf blade	From appearance of tip until leaf blade was dry
5	16.3	19.8	15.3	51.4
4	16.9	20.1	20.0	57.0
3	13.9	22.6	21.1	57.6
2	11.1	22.8	18.5	52.4
1	7.9	21.9	9.6	39.4
Average	13.2	21.4	16.9	51.5

*Leaf 5 is the fifth one below the head and 1 is the leaf next to the head.

Approximately the same number of days are required for the fifth and fourth leaves below the head to emerge completely. From this time on, however, successive leaves emerge within progressively shorter periods of time. This is due, in part at least, to the increasing rate of growth of the internodes of the culm. (See footnote 6, p. 942. The leaves of the culm not only grow upwards, but they are also pushed from within the enclosing leaf sheaths as a result of the rapid elongation of the internodes.

Corresponding data from the shoots of the other strains of timothy which were studied show that, in general, the progesss of development of the different leaves was about the same as for ordinary timothy. The time required for the uppermost leaf to emerge varied, however, as follows: for ordinary timothy, 7.9 days elapsed from the time its tip appeared until the blade was completely emerged; on the shoots of the early selection, 11901, this time was reduced to 4.9 days; and on the shoots of the late selection, 15167, it was increased to 11.6 days.

NUMBER OF DAYS LEAVES REMAIN GREEN

Although the uppermost leaf is the last to appear, it remains green for a comparatively short time and becomes dry several days earlier than the second from the upper leaf. This was true for all strains. In some instances, especially in the late strain, the blade of even the third leaf below the head remained green until a later date than the uppermost leaf. With these exceptions, the leaves became dry in succession from the base toward the tip of the shoot in the same order in which they appeared.

Table 3 shows the number of days required for the average leaf on the shoots of each strain of timothy to emerge completely after its tip had appeared, the number of days the leaf blade remained entirely green, the number of days for it to become entirely brown after its tip began to dry, and the total number of days elapsing from the time its tip appeared until its blade was finally dry and brown.

The average date at which the five upper leaves of the early selection, 11901, appeared was 2.7 days before the date of appearance

TABLE 3.—*Average time for the upper five leaves on the shoots of different strains of timothy to emerge, remain green, and become dry.*

Strain	Average number of days			
	From time tip appeared until blade had entirely emerged	From time blade had fully emerged until drying began at tip	Required for complete drying of leaf blade	From appearance of tip until leaf blade was dry
Early, 11901	12.0	24.7	16.3	53.0
Medium, ordinary	13.2	21.4	16.9	51.5
Late, 15167	13.6	27.9	17.3	58.8

of the corresponding leaves of ordinary timothy. However, the leaves of 11901 remained green for 1.5 days longer than those of ordinary timothy. Although 11901 was in full bloom 4 days earlier than ordinary timothy, yet the leaves of the early selection became dry only 1.2 days sooner than the leaves of the ordinary strain.

On the shoots of the late selection, 15167, the average leaf appeared 4.8 days later and remained green 7.3 days longer than the leaves of ordinary timothy. Consequently, although the plats of 15167 were in full bloom only 5 days later than the plats of ordinary timothy, yet the leaves of the late selection remained green 12.1 days later than the leaves on the shoots of the ordinary strain.

NUMBER OF GREEN LEAVES ON DIFFERENT STRAINS AT DIFFERENT TIMES

Table 4 shows the number of leaf blades entirely green or partially green on each one of eight dates when samples of the hay were collected for the purpose of determining the percentage of green color and the grades assigned the hay.

The total number of green leaves decreased as the season advanced. The decrease in the area of green leaf tissue was even more rapid than the figures representing the total number of green leaves indicate for the reason that the proportion of leaves with blades entirely green gradually decreased and the proportion of leaf blades which were only partially green increased.

Up to June 19 the number of green leaf blades on the shoots of the early selection was equal to, or even somewhat larger than, the number on the shoots of ordinary timothy. This may be attributed, in part, to the tendency for the blades of the leaves of the early selections to remain green for a somewhat longer time than the leaves of ordinary timothy. On and after June 28, the number of green leaves was slightly less on the shoots of 11901 than on those of ordinary timothy.

On the shoots of the late selection there were greater numbers of green leaf blades at all times than on the shoots of the other two strains. This was due both to the later time at which the leaves de-

TABLE 4.—*Average number of leaf blades entirely and partially green at different times.*

Date	Condition of leaf blade*	Strain		
		Early, 11901	Medium, ordinary	Late, 15167
June 4	G G-B	4.4 1.3	4.4 1.1	5.1 1.0
Total.......		5.7	5.5	6.1
June 10	G G-B	3.7 1.6	3.7 1.6	5.4 0.7
Total		5.3	5.3	6.1
June 19	G G-B	2.9 2.1	3.0 1.7	5.2 1.0
Total		5.0	4.7	6.2
June 28	G G-B	0.8 2.3	1.3 2.0	2.9 2.1
Total . ..		3.1	3.3	5.0
July 5	G G-B	0.4 2.3	0.5 2.4	1.7 2.4
Total		2.7	2.9	4.1
July 8	G G-B	0.2 2.1	0.3 2.2	1.2 2.6
Total........		2.3	2.5	3.8
July 17	G G-B	0.0 0.8	0.1 1.0	0.3 2.3
Total........		0.8	1.1	2.6
July 29	G G-B	0.0 0.0	0.0 0.1	0.0 0.7
Total........		0.0	0.1	0.7

*G = leaf blade entirely green; G-B = leaf blade partially green, partially brown.

veloped on the shoots of the late selection, and also to the greater number of days during which the leaf blades remained green on the shoots of the late than on the shoots of the early or medium strain.

COLOR AND GRADES OF HAY

Samples of hay produced by each strain collected on different dates distributed at fairly uniform intervals from June 4 to July 29 were classified according to color and grade (Table 5).[7]

[7]These samples were classified by the Hay, Feed, and Seed Division, Bureau of Agricultural Economics, U. S. Dept. of Agriculture.

TABLE 5.—*Color, grade, and protein content of samples of hay produced by early, medium, and late strains at different dates in 1935.*

Date of harvest	Strain	Color reading or hue	Green color, %	U. S. class and grade	Protein, %
June 4	11901	9.50y	100	U. S. No. 1 Extra Green Timothy	13.13
	Ordinary	9.52y	100	U. S. No. 1 Extra Green Timothy	12.50
	15167	9.23y	100	U. S. No. 1 Extra Green Timothy	14.69
June 10	11901	9.32y	100	U. S. No. 1 Extra Green Timothy	10.13
	Ordinary	8.57y	100	U. S. No. 1 Extra Green Timothy	10.56
	15167	9.12y	100	U. S. No. 1 Extra Green Timothy	11.63
June 19	11901	8.98y	100	U. S. No. 1 Extra Green Timothy	8.69
	Ordinary	9.50y	100	U. S. No. 1 Extra Green Timothy	10.06
	15167	9.51y	100	U. S. No. 1 Extra Green Timothy	10.88
June 28	11901	6.67y	76	U. S. No. 1 Extra Green Timothy	7.94
	Ordinary	7.80y	100	U. S. No. 1 Extra Green Timothy	7.50
	15167	8.81y	100	U. S. No. 1 Extra Green Timothy	9.44
July 5	11901	6.49y	71	U. S. No. 1 Extra Green Timothy	6.06
	Ordinary	7.14y	91	U. S. No. 1 Extra Green Timothy	6.38
	15167	7.62y	100	U. S. No. 1 Extra Green Timothy	9.44
July 8	11901	6.41y	69	U. S. No. 1 Extra Green Timothy	6.63
	Ordinary	6.61y	74	U. S. No. 1 Extra Green Timothy	5.81
	15167	7.04y	88	U. S. No. 1 Extra Green Timothy	6.63
July 17	11901	4.29y	43	U. S. No. 2 Timothy	6.31
	Ordinary	5.81y	58	U. S. No. 1 Timothy	6.31
	15167	6.05y	61	U. S. No. 1 Extra Green Timothy	6.63
July 29	11901	3.47y	35	U. S. No. 2 Timothy	6.50
	Ordinary	3.68y	36	U. S. No. 2 Timothy	7.81
	15167	5.64y	56	U. S. No. 1 Timothy	7.19

Table 5 shows that as the season advanced and the number of green leaves on shoots with heads decreased, the color reading or hue also gradually decreased. Even after the leaf blades on the shoots with heads were entirely dry, some green color remained in their leaf sheaths and stems.

Up to July 8 all samples of the early, medium, and late strains produced U. S. No. 1 Extra Green hay. On July 17 the early strain produced a No. 2 grade, the medium strain a No. 1 grade, and the late strain still produced U. S. No. 1 Extra Green hay. These samples were cured in a barn where they were not exposed to the sun and dew. If they had been cured under ordinary field conditions, the probabilities are that they would have been rated lower than No. 1 Extra Green at somewhat earlier dates than these records show.

PROTEIN CONTENT OF THE HAY

In general, the later the florets bloomed on the plants of any strain of timothy, the higher was the percentage of protein in the hay, as

shown in Table 5. The protein data are based on analyses made on hay containing from 6.51 to 7.55% of moisture and an average of 7.04%.[8]

With minor exceptions, the hay produced by the late selection was consistently higher in protein content than the hay of either the early selection or of ordinary timothy. During the period from June 14 to June 24, F. C. 15167 contained an average of 1.90% more protein than ordinary timothy and during the period from June 26 to July 11, 1.28% more. During these two periods the late selection contained as high a percentage of protein as ordinary timothy contained about 7 to 9 days earlier. The higher percentage of protein, the greener color, and the higher grade of hay produced by the late selection may be attributed to the later dates at which the leaves appeared and to the longer time that each leaf remained green.

It has been shown that the quantities of vitamins B and G are also directly correlated with the degree of green color and the percentage of protein in the hay.[9]

SUMMARY

In 1935 a study was made of the growing habits of the leaves on the plants of three strains of timothy and of the relation of their condition to the quality of the hay. These strains included ordinary timothy which blooms and matures at a medium date, an early strain, and a late strain, each of the selections representing three generations of selections for earliness or lateness and for the tendency for the leaves to remain green as the seeds approached maturity.

In the plats of both the early and the late selection the leaves remained green for a longer time than in the plats of ordinary timothy.

Although the plats of the early selection were in full bloom 4 days earlier than the plats of ordinary timothy, the leaves became dry only approximately 1.2 days sooner than the leaves of ordinary timothy.

The plats of the late selection were in full bloom 5 days later than the plats of ordinary timothy. The leaves appeared 4.8 days later and remained green 7.3 days longer and therefore approximately 12 days later than the leaves of ordinary timothy.

As the season advanced, the color reading of the hay from samples of all strains showed a constant decrease in the hue of the hay which indicates the degree of greenness in the grades of hay and in its protein content. These values, correlated with the number of green leaves on the stems, were generally higher for the late selection than for either the early selection or ordinary timothy.

[8]The protein determinations were made by the Department of Agronomy of the Ohio Agricultural Experiment Station.

[9]HUNT, C. H., RECORD, P. R., and BETHKE, R. M. Effect of the stage of maturity and method of curing upon the vitamin B and vitamin G content of alfalfa, clover, and timothy hay. Jour. Agr. Res., 51:251–258. 1935.

ROW COMPETITION AND ITS RELATION TO COTTON VARIETIES OF UNLIKE PLANT GROWTH[1]

N. I. HANCOCK[2]

IN cotton variety trials it is customary to plant three- and four-row plats of each variety and to harvest the middle row or rows for the data on yield. The assumption is made that the border rows will be affected by an unequal vegetative growth and these rows are therefore discarded.

The planting of these extra rows requires additional expense of labor and time as well as either spreading the experiment over a larger area of land or reducing the number of replications. Is the magnitude of the error attributed to unlike plant growth large enough to justify the planting of these extra rows?

The border effect at the ends of rows or along the sides of the area in the experiment are well recognized and are not a part of this problem. The need of buffer rows in experiments where different fertilizer treatments are given is fully granted. The unequal spacing of plants may be of importance in its effect upon row competition. In the immediate problem the variable factor is unlike plant growth. Fertilizer treatments, spacing, and cultural methods were made alike as nearly as it is possible to do so under field conditions.

A great deal of work on unequal plant growth and its relation to row competition has been done on small grains, but there are very few experiments reported on cotton. Ligon (4)[3] measured the variation when different size plats of 100-, 200-, and 300-foot rows were used. The probable errors are calculated by the "deviation from the mean" method of Hayes. A brief summary of the three-row plats 100 feet long is given in Table 1. In this table it is seen that the variation of the middle row is not consistently less than that of the outside rows.

TABLE 1.—*Variation of outside rows compared with middle row when measured in terms of the probable error, Oklahoma Experiment Station.*

Row	1925	1926	1927
Outside....	5.55	4.99	6.99
Inside....	4.96	6.37	5.61
Outside....	4.89	5.36	6.48

In a paper before the Southern Agricultural Workers Association in 1932, Hale (3) reported that in cotton variety trials in Arkansas and Georgia, border rows produced from 12% to 40% more seed cotton than middle rows of three-row plats, and that the Trice variety yielded 104 pounds more cotton per acre when grown alone than when tested with alternate rows of Cleveland. He did not give any

[1]Contribution from the Department of Botany, Tennessee Agricultural Experiment Station, Knoxville, Tenn. Received for publication August 15, 1936.

[2]Assistant Botanist. Acknowledgments are due Mr. K. T. Hutchinson who supervised the field work at Murfreesboro, and Doctors H. H. Love and George W. Snedecor for their helpful criticisms.

[3]Figures in parenthesis refer to "Literature Cited", p. 957.

data upon the variation of his stands or errors that might have been due to soil heterogeneity. Ware (8) gave results on row competition where the plats were thicker and where they were thinner in stand than the check. Parallel comparisons were made and the significance of the means was tested by both Bessel's and Student's methods. Ware sums up his results as given in Table 2.

TABLE 2.—*The effect of different spacings on row competition. Arkansas Experiment Station.*

1923	Some competition where plats were thicker in stand than check. No competition where plats were thinner in stand than check.
1924	Considerable competition where plats were thicker in stand than check. Considerable competition where plats were thinner in stand than check.
1925	Very little competition where plats were thicker in stand than check. Considerable competition where plats were thinner in stand than check.
1926	Considerable competition where plats were thicker in stand than check.
At Scott	Considerable competition where plats were thinner in stand than check.
1926	Very little competition where plats were thicker in stand than check.
At Mariana	Slight competition where plats were thinner in stand than check.

Christidis (1) measured plant competition in an experiment at the Verria Cotton Substation in Greece during the season of 1932. He used three-row plats 7.35 feet wide and 323 feet long so that the rows were approximately 2.5 feet wide. The plants were spaced 11.5 inches apart, two plants to the hill. There were five randomized blocks and the varieties were repeated twice in each one. By "Analysis of Variance" he found Z equal to .407 as compared with Z equal to .335 at P = 5% in Fisher's table, and therefore there was a significant difference due to competition. The rows were spaced closer than is the usual custom in this country and may account in part for the effects due to competition.

PLAN OF PRESENT EXPERIMENT

The present experiment was planted for three seasons at Murfreesboro on medium rich upland soil designated as Decatur loam and for the fourth season at Knoxville on upland of similar productiveness designated as Cumberland loam. The rows were 72 feet long and 3 feet on each end were discarded, leaving 66 feet as the length of row harvested. All rows were 3 feet wide, so that a single-row plat represents 1/220th of an acre. The same fertilizer treatment was given all rows, and as nearly as possible the same spacing of plants. Two border rows were planted along each side of the experimental area.

Since unlike plant growth was the variable factor to be tested under field conditions in this experiment, it was important that varieties be chosen which differed materially in this respect. In 1928 and 1929 strains from every cotton-growing state, except Arizona and New Mexico, were in the trials. Of these strains, California Acala and Delfos 6102 appeared to be the most different in plant growth.

California Acala is a selection of the Acala variety which originally came from Acala Province, Mexico. It is late-maturing, tall, vigorous-growing, semi-spreading, large boll, large leaf, and non-prolific. Delfos 6102 was originated in Mississippi as a selection of Foster. It is fairly early, semi-dwarf, spreading, small boll, small leaf, and prolific.

The photograph in Fig. 1 was taken in late October and shows the leaves retained by the Acala plants as opposed to the complete shedding of Delfos. A fairly accurate picture of the differences in plant growth may also be seen. Some measurements on these varieties are given in Table 3.

TABLE 3.—*Vegetative and other measurements of California Acala and Delfos 6102 cotton.*

Measurements	No. of samples	Calif. Acala	Delfos 6102
1, Length of lint, in.	12	$1\frac{1}{16}$ to $1\frac{1}{8}$	$1\frac{1}{8}$ to $1\frac{3}{16}$
2, Earliness, % 1st picking	12	20.2 to 30.2	32.4 to 41.8
3, Lint %	12	37 to 38.8	30 to 31.5
4, Lint index, grams lint per 100 seed	12	7.51 to 8.46	5.26 to 6.24
5, Size of seed, grams per 100 seed	12	13.8 to 15.6	10.5 to 12.0
6, Size of bolls, bolls per pound seed cotton	12	58.8 to 60.7	81.3 to 87.5
7, Height, in.	1,050	$34.1 \pm .421$	$30.5 \pm .482$
8, Size of leaf, sq. in.	515	$14.8 \pm .142$	$11.1 \pm .133$
9, Vegetative limbs per stalk	100	$1.39 \pm .085$	$1.60 \pm .068$
10, Mean length vegetative limbs, in.	150	$19.1 \pm .055$	$20.2 \pm .024$
11, Fruiting limbs per stalk	100	$12.9 \pm .101$	$13.7 \pm .122$
12, Mean length fruiting limbs, in.	1,290	$9.25 \pm .032$	$10.3 \pm .026$
13, Mean length internodes main axis, in.	100	$2.81 \pm .054$	$2.62 \pm .087$
14, Mean number nodes per fruiting limb	1,290	$2.54 \pm .048$	$3.09 \pm .036$
15, Bolls per fruiting limb	1,290	$0.83 \pm .222$	$1.05 \pm .691$
16, Leaves per stalk	10	81 ± 10.2	112 ± 12.3

Measurements 1 to 6 were taken over a period of two seasons at the three stations. The upper and lower limits are given because the variation would naturally be large under these conditions. The remaining measurements (except 8 and 16) were taken from 100 random stalks of each variety after the cotton was harvested the season of 1934. For measurements 8 and 16, typical stalks of each variety were taken in August, the leaves divided into six groups, and the area measured by the planimeter, so that the area of the leaf is represented by the weighted mean. Measurements of this kind are relative and will vary with the soil and weather conditions under which the varieties are grown, but they give a fair index of the growth differences under the conditions of this experiment.

In the description and discussion that follows the abbreviation A represents a single-row plat of California Acala and D a single-row plat of Delfos 6102. In 1930 and 1931 the two series ADADDD and DADAAAA were repeated 10 times in the planting each season. In 1931 a mistake was made in the planting of one series so that nine of them were harvested. In 1932 and 1934 the two series were changed somewhat; DDDDAD being followed by AAAADA and the two series alternated and repeated 14 times in 1932 and 10 times in 1934. It is noted that the planting arrangement is planned so that the border and middle rows of each variety are not more than three-row widths apart, and one is justified in making parallel comparisons. Thus, from the two series the following combinations may be obtained:

DDD Delfos row between two Delfos rows.

DDA Delfos row, with Acala row on one side and Delfos on other side.

ADA Delfos between two Acala rows.

AAA Acala row between two Acala rows.

AAD Acala row, with Delfos row on one side and Acala on other side.

DAD Acala between two Delfos rows.

The seasonal conditions during these trials are given in Table 4.

TABLE 4.—*Seasonal conditions during the experiments.**

Year	Place	Total rainfall, in.	Mean temperature, °F	Date planting	Date 1st picking
1930	Murfreesboro	6.34	79.1°	May 1	Sept. 27
1931	Murfreesboro	5.45	78.5°	May 4	Sept. 21
1932	Murfreesboro	8.39	79.6°	May 4	Sept. 25
1934	Knoxville	11.92	79.3°	May 2	Sept. 18

*Rainfall and temperature are for months of June, July, and August

The mean yields in pounds of seed cotton are given in Table 5, and along with them are the stands and spacing of the stalks.

It will be seen from Table 4 that 1930 and 1931 were very dry seasons at Murfreesboro, and the yields in Table 5 reflect this condition. The 1932 season at Murfreesboro was a fairly normal one, and 1934 at Knoxville was above the average. The stands given opposite the yields are fairly regular for each combination, except the season of 1932. The stalks were counted after the last picking and represent the actual number that gave these yields. In 1932 the stands of the Acala combinations were uniformly higher than those of Delfos. The spacings may appear somewhat wide to conform with optimum conditions suggested at other stations, but from 12 to 18 inches is the spacing that experiments in this state have shown to give optimum yields. Mooers (5) found that plants adjust themselves in the row to a wide variation in spacing. He states, "that with 3-foot rows 3 inches may be allowed either way from the 'best' spacing without noticeable effect on the yield."

At first reading, the differences in the mean yields of Table 5 appear very small, but it should be recalled that the results are the

TABLE 5.—*Mean plat yield in pounds of seed cotton and mean stand in number of stalks.*

Combinations	Mean plat yield	Mean plat stand	Inches apart	Mean plat yield	Mean plat stand	Inches apart
	At Murfreesboro, 1930			At Murfreesboro, 1931		
DDD	3.68	46.8	16.9	3.50	48.3	16.4
DDA	3.58	49.5	16.0	3.57	44.0	18.0
ADA	3.51	45.2	17.5	3.33	46.3	17.1
AAA	4.57	45.8	17.3	4.47	49.5	16.0
AAD	4.82	46.3	17.1	4.76	48.8	16.2
DAD	4.87	49.5	16.0	5.20	45.5	17.4
	At Murfreesboro, 1932			At Knoxville, 1934		
DDD	4.80	63.3	12.5	8.96	54.9	14.4
DDA	4.71	62.3	12.7	8.88	55.7	14.2
ADA	4.67	62.5	12.6	8.43	55.0	14.5
AAA	4.79	75.7	10.4	8.44	55.8	14.2
AAD	5.03	76.6	10.3	8.45	56.1	14.1
DAD	5.24	78 1	10.1	9.00	56.6	14.0

mean of several plat yields and also that each mean plat yield represents 1/220th of an acre and that a difference of only ½ pound would give 110 pounds per acre. These differences may be seen more clearly by stating them in pounds as in Table 6.

TABLE 6.—*The differences in the mean yields reported in Table 5 as given in pounds.*

Year	DDD ADA	DDA ADA	DDD DDA	AAA DAD	AAD DAD	AAA AAD
1930 ...	+.17	+.07	+.10	−.30*	−.05	−.25
1931..	+.17	+.24	−.07	−.73*	−.44	−.29
1932 .	+.13	+.04	+.09	−.45*	−.21	−.24
1934. .	+.53	+.45	+.08	−.56	−.55	−.01

*Significant

In Table 6 the data are given in terms of the upper combinations. For example: DDD in 1930 made + .17 of a pound more seed cotton than the ADA combination, or AAA in 1930 made — .30 of a pound less seed cotton than the DAD combination, etc. The results show that there is an effect from unequal plant growth. It would be expected that the small, less vigorous Delfos between its own border rows would yield more than where it was placed between the tall, vigorous Acala. Likewise, Acala between its own border rows would have more competition and yield less than where it was placed between Delfos. The consistent positive and negative results (with only one exception) show further that the extreme growth differences of these varieties reacted the same way under the variable seasonal conditions. But is the degree of these effects (as shown by the mean pound differences in Table 6) of the magnitude to cause a serious error in varietal trials?

No consideration as yet has been given the part played by soil variation and other factors that are associated with field trials. Since in 1930 and 1931 the mean yields are the result of paired observations, the significance of the difference between them may be tested by Fisher's (2) formula for t, *viz.*, $t = \frac{x\sqrt{n}}{s}$, and the t value given for each mean difference. In this case, however, the variance of all the differences for the season can be calculated and the error for the mean of any 10 differences obtained. The mean square or variance of the 1930 difference is .2514; therefore $\sqrt{.2514/10}$, or the standard error of the mean of any 10 differences among the combinations, is .158. For 54 degrees of freedom, $t_{.05}$ equals 2.008; .158 x 2.008 is .31 of a pound, which is the least significant difference for the combinations in 1930. The combination AAA-DAD is fairly significant. The variance of the 1931 differences is .5751 and the standard error of the mean of any nine differences is .252. For 48 degrees of freedom t equals 2.008; .252 x 2.008 is .50 of a pound, which is the least significant difference for the combinations in 1931. Again the AAA-DAD combination is of significance.

It will be noted that the experimental design was changed for the seasons of 1932 and 1934, and the analyses of data are given in Table 7. It would hardly be possible to randomize completely combinations of the kind in this experiment. The series were reversed throughout the planting area and the two series constitute a block as given in this analysis.

TABLE 7.—*Analyses of variance of yields in 1932 and 1934.*

Source of variation	1932 at Murfreesboro			1934 at Knoxville		
	Degrees of freedom	Sum of squares	Mean square	Degrees of freedom	Sum of squares	Mean square
Total	83	34.08	.	59	135.96	...
Blocks	6	20.44	..	9	88.99	..
Variety	1	1.80	1.80	1	0.25	0.25
Combinations in Delfos	2	0.11	0.05	2	1.62	0.81
Combinations in Acala	2	1.47	0.73*	2	2.09	1.05
Remainder (error)	72	10.26	0.14	45	42.98	0.95

*Significant.

In Table 7 it is observed by the mean squares that only the combinations in Acala at Murfreesboro in 1932 show significant differences. The standard deviation for the mean combinations in 1932 is $\sqrt{.14\,(1/14 + 1/14)}$ and equals 0.14 pound. For 72 degrees of freedom $t_{.05}$ equals 1.994; 1.994 x .14 is 0.28 of a pound, which is the least significant difference for the combinations in 1932. In Table 6 only the AAA-DAD combination exceeds this amount. In 1934, the standard deviation of the mean combinations is $\sqrt{.95\,(1/10 + 1/10)}$ and equals 0.44 pound. For 45 degrees of freedom, $t_{.05}$ equals 2.014;

2.014 x .44 is 0.89 pound, which is the least significant difference for the combinations in 1934. Reference to Table 6 shows that no 1934 difference equals this amount.

A further examination of the 1932 data in Table 5 shows that the stands of Acala are uniformly higher than those of Delfos. With the particular plantings that had to be used in this experiment and with extreme differences in growth habits, unequal spacing of the plants might exert considerable influence upon the yields. The association of stand with yield of the 1932 data may be tested by the method suggested by Snedecor (6), and the results are given in Table 8.

TABLE 8.—*Analysis of covariance, 1932, Murfreesboro.**

Source of variation	Degrees of freedom	Mean square error of estimate
Between mean of blocks	5	3.128
Between Delfos combinations	1	0.01
Between Acala combinations	1	0.04
Between varieties	1	0.01
Remainder (error) .	71	0.135

*This table is included through the courtesy of Professor Snedecor

Evidently the factor of unequal stands entered in as a part of the influence on the combinations and varieties in 1932, for neither of them now show significant effects of plant competition.

A FURTHER NOTE ON PLANT COMPETITION

The results of a varietal test conducted jointly by the Tennessee Experiment Station and the Division of Cotton and Other Fiber Crops and Diseases, U. S. Dept. of Agriculture, in 1935 are given in Table 9. This test was placed on medium fertile soil and planted by the randomized block method. There were four blocks and four-row plats The rows were 100 feet long and 3 feet wide. The plants were spaced every 10 inches.

TABLE 9.—*Yields of cotton at the U S Cotton Field Station, Knoxville, Tenn., 1935.*

Varieties	Mean plat yields, lbs.		
	4 rows	2 inside rows	2 outside rows
Delfos 719	17.68	9.23	8.45
Acala 44-5-2118	17.65	8.75	8.90
Trice W-2-1 .	17.54	8.67	8.87
Stoneville 2-A.	14.83	7.45	7.38
Cleveland 884—St. 4.	13.93	7.33	6.60
Acala 1144.	12.63	6.30	6.33
D. P. L. 11-A. .	10.13	5.08	5.05
Farm Relief, St. 3	9.95	5.15	4.80
S. D....... . ..	1.64	1.02	1.08
Least significant difference, at 5% level...	2.91	1.56	1.62

The eight varieties were randomized with a single restriction, and the data on the four-row plats, the two inside-row plats, and the two outside-row plats were analyzed separately by "analysis of variance".

It will be seen that the ranking of the varieties is not materially different whether the four-row, the two inside-row, or the two outside-row plats are chosen to represent them.

DISCUSSION

It will be recalled that the two varieties selected for this experiment differed very materially in their vegetative growth. The mean difference as given on the measurements in Table 3 may at first appear very small, but assuming that means of this kind will approach the normal curve of error the test for significance may be made by the usual formula $\sqrt{\sigma_1^2 + \sigma_2^2}$. By this criterion it will be seen that the differences between the two varieties in most instances are materially significant.

FIG. 1.—Center row Delfos 6102 flanked on both sides by Acola.

It might be argued that the total differences in the vegetative measurements would be negligible, but if an assumption of this kind is correct it is doubtful that two other varieties could be found among the upland strains commonly grown that would give significant total differences.

The retention of the leaves by Acala, as shown in Fig. 1, as opposed to the early shedding of Delfos leaves should give a large difference in the metabolism of these two varieties. This in turn might have affected the root development.

It is the general custom on the upland soils to space the rows 3 feet and on the richer soils 3½ to 4 feet, so that the 3-foot rows used in this experiment probably represent the lower limit of row width that is practicable to produce row competition. An extension of row width should give a higher degree of negative influence.

It has been seen that the stands were fairly uniform in all seasons except 1932, and there is no assumption that they entered in as a factor except in 1932.

It is true that the 1930 and 1931 seasons at Murfreesboro were very dry and that neither variety made exceptional growth. But under these circumstances it would be expected that the more vigorous Acala would have taken more advantage of the soil moisture than the yields indicate.

The question may be properly asked where one has a given area of land on which to test a number of cotton strains, which of the two will cause the largest error in the trials, land heterogeneity or row competition? If the land is very fertile, row competition might increase the error seriously, but on medium fertile soil, as under the conditions of this experiment, it is suggested that more replications be used and that land heterogeneity is the more serious error to overcome. Stephens (7) has given an able discussion on lowering the error due to land variations.

In Table 9, where the varieties were randomized, the error due to plant competition was also randomized and evidently did not affect the results.

In Table 6 it is observed that (with one exception) all the Delfos combinations are positive and all the Acala combinations are negative when taken over the 4-year period; therefore competition would be an additive factor and a bias would result if the average were taken over a period of 4 years.

In this table it is further observed that Delfos with Acala on only one side, and *vice versa*, showed very small differences when compared with themselves between their own border rows. For instance, DDD averaged over the 4-year period only 1.4% more seed cotton than DDA and AAA 4.01% less seed cotton than AAD. In other words, where two rows of the same variety are planted, presumably only one side would be affected by a different variety, and in this experiment the effect is very small. So it is suggested that two-row plats be used for testing cotton varieties on medium fertile land. The picker is accustomed to harvesting two rows at a time, and it simplifies the method of planting as well as the recording of weights.

SUMMARY

1. Measurements are given to show that the California Acala and Delfos 6102 varieties used in this experiment differ materially in their morphological characters.

2. An attempt was made to induce row competition by planting these varieties in different combinations of single-row plats so that full and partly full expressions of their plant growth might be reflected upon each other.

3. The experiment was carried on over a period of 4 years and each combination was in the trials 43 times during this period.

4. The experiment showed effect from the unequal plant growth as given in Table 6, and that plant competition in cotton would become an additive factor if the average were taken over a period of years.

5. For a given season, however, the degree of this effect was small and not significant in the Delfos combinations; in most instances

it was fairly large in the Acala combinations, but the significance is small as measured by the given mathematical methods.

6. It is suggested that two-row plats be used for cotton varietal trials on medium fertile soil.

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AGRONOMIC AFFAIRS

MEETING OF NORTHEASTERN SECTION

THE Northeastern Section of the Society held its annual meeting at the West Virginia Experiment Station at Morgantown June 24 and 25. A special session to discuss the completion of the soil survey was held the evening preceding the regular meeting. After an informal discussion, a committee was appointed to formulate a statement and resolutions for presentation to the business session. The following resolution was presented and adopted:

RESOLUTION ON COMPLETION OF THE SOIL SURVEY

From: The Northeastern Section, American Society of Agronomy

To: The Committee on Station Organization and Policy

The importance of the Soil Survey, as an inventory of our soil resources, as the basis of better land use, and of sound adjustments in farming, requires no argument. The present intense interest in the soil as a national resource has emphasized the need for completing the soil survey as soon as possible.

To this end we heartily endorse and support the efforts of the Committee on Station Organization and Policy, and urge vigorous and prompt action on their part. We offer the following suggestions for consideration:

1. That a joint committee be created, representing both the United States Department of Agriculture and the State Stations.

2. That to make the survey of the greatest value and usefulness each state must take an active part in the mapping and the interpretation.

3. That a determined effort be made to coordinate the aerial photography of the several federal and state agencies to the end that more needs will be fulfilled.

4. That the Agricultural colleges take steps to train, both in course and apprenticeship, men qualified for survey work.

5. That the salary scale in the Survey be such that qualified and experienced men may be kept in the service.

This resolution was adopted by the Section.

The West Virginians proved genial hosts to the fifty guests from outside the state. The program included inspection of the corn and sweet clover breeding and the small grain nursery and pasture experiments at Morgantown; the Reedsville Homestead project, including extensive vegetable and grain fertilization experiments; and, on the day following, breeding, rotation, and fertilizer experiments with a wide variety of crops at the substation along the Ohio River at Lakin. On June 26 several members were the guests of the Dupont Nitrogen Plant at Belle, W. Va.

President J. A. Bizzell presided at the business meeting following the banquet at the Country Club at Morgantown on the evening of June 24. Dean F. D. Fromme welcomed the group In recognition of their many years of interest in and services to the Northeastern Section of the American Society of Agronomy Honorary Life Membership was proposed and unanimously voted for Dr. H. J. Wheeler and Dr. B. L. Hartwell, both formerly directors of the Rhode Island Experiment Station, and Dr. G. E. Simmons, now Professor Emeritus of the University of Maine.

The Nominating Committee presented the following list of officers for the ensuing year who were duly elected: President, R. P. Thomas, University of Maryland; Vice-President, R. J. Garber, Director N. E. Laboratory for Pasture Research, State College, Pa.; and Secretary-Treasurer, J. S. Owens, Agronomy Department, Connecticut State College, Storrs, Conn.—J. S. Owens, *Secretary*.

CANADIAN SEED GROWERS' ASSOCIATION

THE Annual Report of the Canadian Seed Growers' Association for 1935–36 was recently distributed by the Association from its headquarters in Ottawa.

In addition to a summary of the proceedings of the business meeting, reports of committees, and other miscellaneous matter, the following papers are published in full: "The Origin and Development of the Canadian Seed Growers' Association," by L. H. Newman; "The Work of the Canadian Seed Growers' Association, Its Objective and Plan of Operation," by R. Summerby; "The Use of Registered Seed in the Scheme of Canadian Agriculture," by H. G. L. Strange; "The Present Policy of Registration of the Several Groups of Crops," by W. T. G. Wiener; "The Use of Registered Seed," by W. J. W. Lennox; "The Rudiments of Pollination and Fertilization of Farm Crops," by W. H. Wright; "An Analysis of Some Varieties of Oats Grown in Nova Scotia," by Kenneth Cox; "Root Seed Production," by L. C. Raymond; and "The Value of Standard Seed Stocks in Root Seed Production",by W. T. G. Wiener.

F. W. Townley-Smith of Lashburn, Sask., was elected President succeeding Professor Robert Summerby of Macdonald College.

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AN AGRONOMIST LOOKS AT LAND USE[1]

ROBT. M. SALTER[2]

IN the changing world of today agriculture seems to have lost its tactical advantage in competition with other groups. During the past century industry has doubled and redoubled many times its production of goods. Not only has production per worker been enormously increased, but there has come a vast increase in the number and variety of its products. These, modern man has learned first to want, then to demand. No longer has agriculture a corner on the wants of the human race.

While industry has been pyramiding its contribution to the wants of man, agriculture has failed to interest him in eating and wearing more than he ate and wore a century ago, if quite as much. True, agriculture too has increased its output per worker. It has borrowed the machine from industry and put science to work on the farm. True also, agriculture has profited by rapid increase in the number of people in industry and commerce, an increase resulting in no small degree from the migration of its own youth to the city. Increased output per worker on the farm and a rapidly expanding ratio of urban to farm population both have been powerful buffers against the growing advantage of industry. Largely to them do those in agriculture owe such opportunity as they have had to share with other groups the material blessings of an industrial age. In the years just past we have been privileged to see just how vital to agriculture has been this expansion in industry.

American agriculture first felt the impact of industrialism in the decades following the civil war when rapid expansion on to virgin land, made possible by the building of the railroads, and the multiplication of the output of the individual farmer through the introduction of farm machinery (both the products of industry), caused the production of agriculture to outrun the demand for its goods. Prices fell to low levels and farmers suffered, but, fortunately, their wants were simple and inexpensive compared with those of their children of today.

[1]Presidential address delivered before the twenty-ninth annual meeting of the Society held in Washington, D. C., November 19, 1936.

[2]Chief of the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio.

About the turn of the century there came a change. Cheap food had stimulated the growth of industry and of cities, both in America and in Europe. Europe needed and was glad to buy this cheap food. Expansion of agriculture slowed down owing to the growing scarcity of suitable new land. Immigration attained enormous proportions. The demand for farm products caught up with production. Farm prices began to rise and with them the value of land. Farmers prospered and city people complained about the high cost of living. City-reared youths went to agricultural colleges and then into farming. Then came war and with it the skyrocketing of farm prices and the patriotic urge to produce more and more food. Land speculation drove land prices to undreamed of heights. Millions of acres of grassland were plowed and put into crops. Farmers bought tractors and other machines as never before. Agriculture seemingly came into its own.

But this agricultural Utopia was short lived. What happened in the post-war depression, in the years which followed, years of industrial boom but continued depression for agriculture, and the precipitous collapse of agriculture during the depression is an old story to all. You know how, even before the debacle of 1929, the foreign markets for American agricultural products withered and dried up under the influence of trade barriers resulting both from a growing nationalism in Europe and tariff wars aided and abetted by our own industrialists. You know how the agricultural production of our former customer countries was increased, far above pre-war levels, how deadly became the competition for what world markets were left from vast new agricultural regions in Australia, South Africa, and the Argentine developed during the war and with machines made in America. You know what happened when the depression finally broke upon us—the contraction in industry, unemployment, the shrink in domestic consumption of foods and textiles, the sustained production of agriculture, surplusses, ruinously low prices, stubbornly high taxes and interest rates, mortgage foreclosures, suffering and incipient revolt on the farm, the fiasco of the Farm Board, the holiday on mortgage foreclosures, new Federal credit agencies for agriculture, the AAA, the drouth years, the Agricultural Conservation Program, and the land use movement.

The land use movement is the child of agricultural distress. In the post-war years, when agriculture was lagging farther and farther behind industry, there grew in the minds of many the conviction that the ills of agriculture were not alone the result of external maladjustments, but that agriculture was really suffering internally as well, and that one need, regardless of what else, was a new land policy in America befitting its maturity. After the depression struck and agriculture had begun its precipitous decline toward the economic cellar, it appeared that the time for action had arrived. In November, 1931, the first "National Conference on Land Utilization" was called jointly by the Secretary of Agriculture and the Executive Committee of the Association of Land Grant Colleges and Universities. In his foreword to the printed proceedings of this conference Secretary Hyde said, "The panorama of overproduction, serious maladjustment in taxation and credit, a radical transformation in the geography of pro-

duction, a greatly changed out-look with regard to population increase and land requirements, and withal the widespread human distress growing out of these dislocations, all emphasize the need for action." In the five years since this conference was held we have witnessed the growth of a new philosophy of approach to the problems of agriculture, a philosophy which has diffused to the geographical limits of the nation and permeated the thinking of numerous and diverse groups concerned with rural life in America. The essential thesis of this philosophy is that for each acre of land and for each farm there is some use pattern which will best serve the welfare not alone of the farmer, but of agriculture as a whole and of the nation as well. It is maintained that this philosophy has provided, for the first time, a common focus for attack on the problems of agriculture and a common denominator by which to measure objectives.

The greatest strength and, I submit, also the greatest weakness of the land use movement lies in the fact that it is premised on *planning*. Strength, in that land use planning implies collective thinking on problems that are not really dissectible; the integration of viewpoints—agronomy, animal husbandry, engineering, farm management, forestry, economics, sociology, etc.; a balanced interpretation of pertinent facts; a basis for coordinated action. Potential weakness, in that land use planning in its broader aspects assumes that it is within the power of the human intellect to evaluate and interpret all of the complex forces which affect the use of land and life on the land, and further, that someone possesses enough prophetic vision to project these evaluations and interpretations into the future. I believe it fair to ask, if, in the present analytical approach to the land use problem, there is not danger that we become too ambitious, that we aim at the impossible and perhaps land in the mire of confusion.

There are even some who look to improved land use for the solution of the entire farm problem. They cannot escape disappointment. Proper land use, although an important step, is not a panacea for the ills that beset American agriculture. It cannot overcome the disparity of agriculture resulting from the comparatively elastic demand for the products of industry or from industry's advantage in tariff protection. It cannot reduce the exhorbitant costs of distribution which today consume two-thirds of what the consumer pays for agricultural products. It cannot recover the wealth that has been drained from the country to the city by inheritance or by the movement of farm-reared youth off the land. It cannot solve the stupendous problem of farm tenancy. It cannot alter the fact that there are double the number of farmers and probably twice as much land as needed to supply the present demand for agricultural products. In itself it can do little to fulfill the crying need for greater outlets for the products of the land. Most of these problems transcend the scope of land use. They lie rather in the field of political economy.

If I interpret aright present thought on land planning, it may be expected to proceed substantially in the following four steps:

1. Determination of the prospective needs, both total and regional, for the varied products and services of land and the interpretation of these in terms of land requirements.

2. The inventory and classification of all the complex physical and human resources of the land, considered not only as they exist today but also in terms of future potentiality.
3. Determination of what rearrangement of land use and of people is needed to yield the particular pattern that will best supply the needs for products and services and at the same time contribute in largest degree to the welfare of the people, both on and off the land.
4. The design of ways and means, through education, legislation, etc., to effect this rearrangement and to keep it synchronized with changing conditions.

I should be the last to question the philosophic accuracy of those who would attack the land use problem in this fashion. Neither should I deny that, granting accomplishment, this scheme would yield maximum benefits. I am quick to admit that the searching analysis of all the intricate factors affecting land use in America, necessary in such an approach, might uncover principles of great value for the establishment of broad policies. But, as contemplated by a mere agronomist, the whole problem looms so terrifically complex, so fraught with intangible and indeterminate factors, so replete with conflicting interests as among regions of production, among human strata on the land, and between agriculture itself and other groups, that I admit a growing fear that the equation of land use contains too many unknowns to permit its solution by direct method.

Not the least disturbing is the implied need for anticipating the future. How far can past trends be extrapolated safely? How anticipate the demand for agricultural products in the face of the uncertain industrial situation resulting from technological unemployment? Who can predict when there may come an explosion in international politics which will greatly affect the outlet for American farm products? On the side of production, what allowance shall be made for improved technology in agriculture, hybrid corn, for instance? Shall we count on the continuation of record breaking seasonal abnormalities? When will new crop pests appear to change the picture? One is inclined to agree with Thomas Carlyle who introduced his essay on the "Signs of the Times" with the assertion, "It is no very good symptom of nations or individuals that they deal much in vaticination," meaning the forecasting of future events.

Perhaps it is mere lack of vision or of boldness to attack large and complex problems from which springs my lack of faith in the solution of the land use problem by the methods just discussed. Perhaps one should not be discouraged because, in the five years since the land use movement was officially launched, no national plan has appeared despite nationwide interest and a great deal of concentrated thinking. Be that as it may, for some time it has seemed to me that many of the goals of land use, perhaps most of the feasible ones, might be attained more readily by a different approach to the problem, one that may be termed synthetic rather than analytical, one in which the individual farm and the individual farm family become the starting point rather than the nation's land and all the people. In such an approach, the collective thinking of those specialized in different

phases of agriculture and land use would be focused on the problems of the individual farm and farmer, considering these in relation to the more or less immediate physical, economic, and social environment, or such elements of it as can be evaluated with some degree of accuracy. The horizon would be pushed only as far as there was clarity of vision.

After all, regardless of how a plan is arrived at, there can be no actual accomplishment in land use until the individual farmer does something about it, and it would seem that the more directly his problem is approached, the more closely the plan ties in to his immediate environment, the more easily may he be induced to act. By this method much time might be saved in getting past mere planning and into the action stage of land use, since solution of the problems of the universe would not be a prerequisite. For that vast area of our land which must continue in agricultural use and for the men who will farm it, this method should meet most of the requirements. There would remain, of course, problems of maladjustment which the individual farmer by his own devices, with such help as government may choose to give him, cannot correct. These, however, would be brought into clearer relief and rendered simpler of attack. After all, such problems as what to do with people on submarginal lands, public reforestation of land, range practices on the public domain, flood control, recreation parks and wild life refuges, are in a sense side shows to the main attraction of agricultural land use and should not be allowed to impede its progress. In approaching land use via the individual farm, agronomists should find real opportunity for service and leadership. It is to this opportunity that I propose to devote my remaining remarks.

In land planning which starts on the farm, the dominant objectives may well be (1) increased efficiency in management and (2) conservation of farm resources. The suggestion of increased efficiency as a legitimate objective is made with full knowledge that collective efficiency in agriculture may exaggerate problems of over-production. To me it seems axiomatic that so long as farming in America is competitive and not collective, so long as we protect the individual's right to a reward in proportion to what use he makes of his talents, efficiency is bound to be a legitimate objective of the individual farmer. That many of the devices which the farmer uses to increase efficiency and lower costs owe their effectiveness to the distribution of over-head charges for capital and labor over a great volume of products cannot change this fundamental fact. Neither is any scheme of solving the problems of surplus production that rewards inefficiency and penalizes efficiency likely to endure long. I cannot refrain from disgressing to point out that the total cost to society of maintaining a given standard of living on the American farm, whether this cost represents money spent for products or subsidies, must vary inversely with the collective efficiency of agriculture. I have no sympathy with the defeatist philosophy of those who would employ inefficiency as a cure for over-production, substituting human toil for the exercise of human intelligence.

The objective of conservation of farm resources, chief of which are

those of the soil, needs no defense before this group. Few today question the imperative need of soil conservation if we would promote the welfare of the present generation of farmers, guarantee opportunity to their children, and maintain the foundation of an abundant life in America. There may be some question as to how much land or just what land is worth conserving, or of what areas should be given preference in the attack on this problem, but these impair in no way the validity of the principle.

Conservation and efficiency have been mentioned as separate objectives in land planning. In reality they are inseparable. Soil conservation and efficient soil management have many elements in common, so many in fact that soil conservation as applied to agricultural land becomes almost the same as efficient soil management with a long-time perspective. It is not surprising that as the new paint wears off the Soil Conservation Service program we see revealed more and more an underlying framework of good agronomy.

Any sound program of agricultural land use must rest on the foundation of improved soil management and cropping practice. The building of this foundation is definitely the responsibility of agronomists. For this task the tools for the most part will be those to which we are already accustomed. The principal change will be one of viewpoint. In the past the tendency has been to advance improved practices more or less independently. What now is needed is the weaving together of improved practices into systems of soil and crop management that best will meet the needs of the farming enterprise as a whole. Interest in the crop will not cease with harvest but will carry through to utilization and market. Obviously this means that agronomists will integrate their program with that of specialists in animal husbandry, in horticulture, in farm management, and in all the other branches into which we have seen fit to divide farming. The social as well as the economic welfare of the farmer will receive consideration, especially on farms that have ceased to provide decent standards of health and living.

A proper starting point for land planning, irrespective of its perspective, is the inventory of the physical resources of land and climate. Those of you who have followed the programs of Soils Sections V and VI have heard able discussions of the different elements which should be included in such an inventory in order that it may serve the various purposes of land use. No review of this discussion will be attempted, but I do wish to emphasize two points which are of special importance when we approach land planning from the viewpoint of the individual farm.

The first of these is that surveys of a reconnaissance type which may serve admirably for the delineation of type-of-problem areas may be wholly inadequate for planning land use adjustments for individual farms within such areas. To serve the latter purpose, surveys necessarily must be refined to a degree that will permit the evaluation of these physical factors for the individual farm and even for the individual field on the farm. This may sound like a large order, but I see no alternative. The surveys made by the Soil Conservation Service in its demonstration project areas are a good example of what is needed generally.

My second point in this connection is that the planning of improved programs of soil management and cropping practice for any farm requires more than a knowledge of soil type, slope, and erosion. Let me illustrate. On the Ohio Experiment Station farm at Wooster we have areas of Wooster silt loam which 40 years of destructive management have reduced to a level of productivity only one-sixth that of other areas of similar soil handled for a similar period under good management. The biotic differences between these areas are probably as great and call for as varying treatment as for soils differing widely in type, in slope, or in degree of erosion. Yet it is doubtful whether a survey including only these elements would differentiate between them. Obviously in such surveys there is need for some quantitative measure of the status of the soil in the scale of chemical depletion. A cover survey properly organized to provide an estimate of the quality of the vegetation would be helpful. It would seem, however, that a more promising and a more direct approach might be found in the application of some of the new rapid chemical soil tests. I seriously commend this idea to those who are responsible for making these basic surveys.

The most difficult, the most challenging part of land use planning is not the inventory phase. After the physical resources are known, after the economic and social environment has been appraised, there remains the really hard job of erecting on this foundation a program of land adjustment that appropriately recognizes all of these factors, one that begins with the land as it exists today and charts the course to the goal of maximum potentiality of farm and farmer. Its tempo must be tuned to the financial and educational level of the man on the land and to the conditions of his tenure. It must satisfy the demands alike of income and conservation. The proper planning of its agronomic features calls for both vision and judgment, for both a thorough understanding of scientific agronomy and an intimate knowledge of the art and practice of farming. Those who have dabbled in this phase of land use appreciate how short is the distance one can travel before he runs off the pavement of established fact on to the uncertain ground of guess and opinion. I know of no other task so well calculated to humble the most arrogant agronomist. Nevertheless, it is the agronomist's job. No one else is as well prepared to interpret the basic characteristics of land in terms not of existing use and practice but of potentialities based on applied soil and crop science. The agronomist's part in land use planning has not always been recognized by those who have attacked the problem.

I have mentioned the need for vision in land planning. Before traditional uses are accepted they should be scrutinized in the light of modern agricultural technology. Otherwise we may find ourselves patching up an unsound structure which really should be torn down and replaced with one of modern design. Let me illustrate. Much hill land in the Appalachian Plateau has been brought to incipient ruin because at the time farming began in this region farmers found it advisable to grow corn on this land, a practice which, correctly or incorrectly, still maintains. Today we are faced with the necessity of retiring some of this land from cropping and on the rest of it resort-

ing to such devices as revamped crop rotations, contour farming, strip cropping and terracing, chiefly in order that we may continue growing corn on these hillsides. Perhaps one may inquire whether in view of what we know today regarding the establishment, the maintenance, the harvesting, and the feeding of high type perennial legume and legume-grass forages, a more economic system of livestock farming might not be developed that would completely eliminate the necessity of growing corn except on level terrace and bottom lands. If this could be done the problem of soil conservation would be much altered and simplified.

In farm planning we think of systems of soil management and systems of cropping. These we gauge not so much by their immediate as by their long-time effects on income and soil productivity. In any system of soil management some practices tend to destroy, others add to the inherent capacity of the soil to produce. Similarly, in any cropping system, some crops tend to reduce and others to increase this capacity of land. Our interest centers not so much in what each element of a given system does as in the net effect of the system as a whole. It would seem that some mechanism by which the effects of individual crops and practices upon soil productivity could be reduced to a common denominator and combined algebraically to show the effect of the system as a whole might be highly useful in land planning. In Ohio we are making use of this idea. To each crop and soil practice is assigned an index, positive or negative, which represents our best estimate of the annual percentage change in soil productivity likely to attend the growth of a particular crop or the use of a particular practice. It is a simple procedure to obtain a combined expression showing the annual effect of a complete system of soil and crop management. In this process allowance is made for soil erosion and for erosion control practices by the application of appropriate factors. The method has been used both in regional and statewide county planning studies. The results have encouraged us to extend its use to individual farm planning during the coming winter. We have even been so bold as to suggest it as a basis for the payment of subsidies for soil conservation, the idea being to graduate payments in proportion as the annual soil productivity index of a farm approaches some chosen standard of performance. Its use for this purpose would have at least two important advantages over the present federal plan. It would eliminate the need for the farm base with its congealing influence on farm practice, and it would pay for honest accomplishment in soil conservation and eliminate the bonus now being paid for past inefficient and destructive soil management. We recognize that such a method of evaluating systems of soil and crop management tends somewhat to over-simplify a complex problem, that the basic factual data are as yet not as complete as might be wished, and that indexes for individual crops and practices will vary with variations in the climatic environment. I have discussed it chiefly because it represents one type of thing agronomists can do in directing land use planning along lines of sound agronomic practice.

As agronomists we cannot readily sidestep the responsibility for seeing that, so far as possible, measures or movements that affect

the handling of the soil or the crops that are grown on it, whether labelled crop control, soil conservation, or land use, do not conflict with good agronomic precepts. We cannot allow our conservatism to keep us aloof from these matters even though they may savor of evangelism or politics. Whether we participate or not, they will be done in the name of our science. Many a worthy cause has been blighted or long delayed when pressed by misguided zealots or by those seeking popular favor. Farmers do not distinguish well between the sheep and goats of bureaucracy. Our job is not alone to seek out facts about soils and crops and to interpret these in terms of sound practice. We have equal responsibility in making them understood by farmers and by those who are attempting to guide farm practice. Some of us have been disturbed by the fact that the national programs of crop adjustment and subsidized soil conservation, programs that should have their roots in sound agronomy, have been so largely planned and manned by those who have only a superficial knowledge of our science. We have been inclined to criticize a good many features of these programs because they would not square with sound agronomy. Perhaps we are not without blame for this. Perhaps we have been too reluctant to assume our share of leadership in these matters.

I have attempted to sketch some of the background of the present agricultural problem. I have proposed attacking land use via the individual farm. I have commented on some opportunities and responsibilities of agronomists in land use affairs. I shall close with a word to the younger members of our Society. Yours will be the major task of making agronomy a living force in the rural life of tomorrow. The land use movement is in its infancy. Decades will be required for its fruition. You will approach its problems unencumbered with the traditions of an era of land exploitation. You will be armed with scientific tools of ever increasing sharpness. Your research will be virile because it will deal with problems that are alive. Your satisfactions will be great, because to the joy which comes from expanding knowledge itself will be added the greater joy of seeing this knowledge used for lifting the level of life on the land. You will learn that the interpretation of science, its translation into terms of useful application, calls for as much ability and offers as great rewards as does the acquisition of new facts

The century which has passed since Liebig said, "Agriculture is of all industrial pursuits, the richest in facts, and the poorest in their comprehension" has done little to alter the truth of that statement. For land use to advance the vital need today, and for long to come, is for more and better interpreters of agricultural science.

DIFFERENTIAL FERTILIZATION IN THE *Bt Pr* LINKAGE GROUP OF MAIZE[1]

C. R. Burnham[2]

A DISTURBANCE of normal mendelian ratios of contrasting characters brought about by a linked differential fertilization gene (Ga_1) has been reported by Emerson (1)[3] in the *Su-Tu* linkage group. A similar gene has been suggested by Eyster and Robinson (2) to explain certain abnormal ratios in chromosome 9. The end result is "differential fertilization," although it may be caused by differences in pollen germination or in pollen-tube growth.

Data are presented in this paper which indicate that similar genes in the *Bt Pr* linkage group may explain certain of the abnormal ratios which have been reported in this group by various investigators. The data are not conclusive on all points but may be useful to others interested in the problem as an indication of certain lines for further investigation.

Hayes and Brewbaker (3) reported abnormal ratios for purple vs. red aleurone (*Pr-pr*) in material segregating for the basic aleurone color factors, A_1, C, and R, concluding that the excess of *pr* grains could be explained by linkage between *Pr* and either *C* or *R*. It seems more probable now that the excess may have been due to a gene, linked with *Pr*, responsible for differential fertilization. Abnormal *Pr-pr* ratios may also result from segregation of the factor pair *In-in* which governs color intensity, or from segregation of the A_2-a_2 factor pair which is linked with *Pr-pr* and is one of four complementary factors known for aleurone color. Rhoades (6) has attributed certain abnormal ratios to a lethal pollen factor (lp) in the *Pr* linkage group.

In the present investigation, other factors in this group which are easily classified were used in addition to *pr*, i. e., *bt* (brittle) and ys_1 (yellow stripe$_1$). Brittle also has the advantage of being closely linked with one of the differential fertilization genes.

OCCURRENCE AND INHERITANCE

During the course of genetic studies, brittle (*bt*) was crossed with a number of different genetic stocks and with one inbred line of dent corn. The segregating progenies from all but three of these crosses gave normal ratios. The crosses which gave the abnormal ratios were with a stock segregating for ys_1, another for yg_1 (yellow-green$_1$), and a Black Beauty pop variety. From the normal crosses 105 selfed ears gave a total of 25.2% of brittle grains. Of these 105 ears, 2 gave significant plus deviations from 25% (3.8, 3.6 times P. E.), while four ears gave significant minus deviations from 25% (3.4, 4.0, 4.0, and

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[3]Figures in parenthesis refer to "Literature Cited", p. 975.

4.2 times P. E.). Progenies from these ears have not been grown, but deviations as frequent and as great as these are not wholly unexpected in a population of that size.

In the other group of crosses, 103 selfed ears gave a total of 15.7% of *bt* grains. Of these ears, 3 gave significant plus deviations from 25%; 36 ears did not give significant deviations from 25%, yet the total percentage of *bt* grains on the ears constituting this latter group was 22.6, a significant minus deviation for the group as a whole which indicates they may belong to a low *bt* group; and the remaining 64 ears gave highly significant deviations with 11.7% of *bt* grains for this group.

As a test of the hypothesis advanced by Rhoades that the low *bt* ratios are due to a lethal factor, in one group plants were selfed and used also as female parents in backcrosses with *bt*, while in another group the plants were selfed and also used as pollen parents in backcrosses. On each of nine plants, two ears were obtained, one of which was selfed and the other backcrossed as the female parent with *bt*. These results, given in Table 1, show that the selfs gave 5.8% *bt* while the backcrosses of the same plants gave 49.6% *bt*, indicating that an ovule lethal was not causing a deficiency of *bt* ovules. The results from the experiment in which plants heterozygous for *bt* were selfed and also used as the pollen parents in crosses with a *bt* stock are given in the second line of Table 1. The selfed ears had 11.9% *bt*, while the backcrossed ones had 56.0%. In the third line are given the results from similar backcrosses of plants which were not selfed. Here the value is 52.7% of *bt* grains. These experiments give no indication that either a pollen or an egg lethal linked with *bt* is causing the deficient *bt* ratios obtained from self-pollination.

TABLE 1.—*Summary of data from reciprocal backcrosses of plants which, when selfed, gave low percentages of bt grains.*

	No. of ears	Selfed ears		Backcrossed as female to *pr bt* male		Backcrossed as male with *pr bt* female	
		Total grains	% *bt*	Total grains	% *bt*	Total grains	% *bt*
Low *bt*	9	2,418	5.8	1,886	49.6		
Low *bt*	4	1,409	11.9			969	56.0
Low *bt*	24	None				7,849	52.7

Crosses and self-pollinations involving two sib plants give some information on the nature of the suggested gametophyte gene and the interaction between stylar tissue and pollen from plants heterozygous for it. In culture 803 (not given in the tables) plant number 12 when selfed produced a low *bt* ratio (14.8%), while plant number 14 when selfed produced a normal *bt* ratio (24.5%); indicating the former carried the differential gene and the latter did not. The cross of 14 female x 12 male produced a normal ratio (24.5% *bt*), indicating that the differential gene is not effective in the pollen unless the stylar tissue also carries the same gene. It must be considered as a dominant

in its action on the stylar tissue; otherwise plants heterozygous for it would not give low ratios when selfed.

For further study, the *Bt* seeds from selfs and crosses were grown and selfed. Comparison of the results from selfing in this second generation showed a highly significant difference between the percentage of *bt* obtained in the selfed *Bt* descendants of the backcross and the selfed heterozygous descendants of the selfed grandparental plant (Table 2). With a single gamete gene operating, the percentages of *bt* in the two groups should be the same. The selfed heterozygous progeny from one selfed grandparental plant produced 10.0% *bt* as compared with the selfs of the backcross progeny which had 4.9%, the difference being 5.1 ± .94%. In the other case where such a comparison could be made, the corresponding values are 10.7% and 6.1%, a difference of 4.6 ± .84%. In each case the grandparental plant was selfed and backcrossed, the above differences appearing in the selfed heterozygous progeny of these two lots of seed from the same heterozygous plant.

TABLE 2.—*Summary of data from the self-pollination of plants heterozygous for bt.*

Culture No. and treatment of grand-parental ear	Genotype	No. of ears	Total *bt*	Total grains	% *bt*	Difference
I. Comparison of data from self-pollination of backcross and selfed descendants of plants which gave low *bt* percentages when selfed						
1045-6 selfed	Bt bt	18	505	5,066	10.0	5.1 ±.94
pr bt x 1045-6 male	Bt bt	44	544	10,999	4.9	
797-7 selfed	Bt bt	6	189	1,774	10.7	4.6 ±.84
pr bt x 797-7	Bt bt	11	161	2,647	6.1	
II. Comparison of data from *pr* and *Pr* (non-crossover *vs.* crossover) classes from the same ear						
1045-6 selfed	pr Bt bt	9	332	2,763	12.0	4.5 ± .66
1045-6 selfed	Pr Bt bt	9	173	2,303	7.5	
1045-7 selfed	pr Bt bt	13	372	2,813	13.2	3.3 ±1.01
1045-7 selfed	Pr Bt bt	4	115	1,161	9.9	
pr bt x 1047-6	pr Bt bt	27	372	7,003	5.3	1.6 ± .44
pr bt x 1047-6	Pr Bt bt	9	102	2,723	3.7	
3523-3 x *pr bt*	pr Bt bt	7	169	1,001	16.9	6.4 ±1.46
3523-3 x *pr bt*	Pr Bt bt	6	149	1,419	10.5	
3950-9 selfed	Pr Bt bt	5	290	1,009	28.7	3.6 ±1.56
3950-9 selfed	pr Bt bt	4	300	1,196	25.1	

These large and significant differences are not readily explainable by a simple differential gamete factor, but can be explained if two such linked factors are operating. Further analysis of these data showed that in the one with the 10.7% *bt*, the *Pr-pr* factor pair was also segregating in the grandparental ear. Comparison of the selfs of plants from the *Pr* and the *pr* classes of seeds showed a significant difference. In the *pr* class the percentage of *bt* was 12.0, while in the *Pr* class it was 7.5, the difference being $4.5 \pm .66\%$. A summary of this and the selfed progeny of other crosses in which the *Pr* and *pr* classes were separated is given in the second part of Table 2.

In four cases out of five the percentage *bt* in the two classes of seeds differs by a significant amount. In all cases one of these classes of seeds is a non-crossover and the other a crossover between the *pr* and *bt* loci. Since the *bt* percentage in the non-crossover class differs from that in the crossover class and is low in both, a second gamete factor was probably operating. The presence of a series of allelomorphs, each with a different degree of effect, might also explain the results. The data from these same cultures (included in Table 4) indicate fairly close linkage between one gamete factor and *bt*. The second disturbing factor cannot be an allelomorph of the first, since only if its locus were close to *pr* could the crossover classes be consistently different from the non-crossover classes, as tested by the percentage of *bt* which these classes produce when selfed; otherwise the two classes would carry the same allelomorph.

The data thus far presented, therefore, indicate that a second gamete factor, located farther from *bt* toward or beyond *pr*, is present in this chromosome in certain stocks. Evidence concerning the location of these genes in the *pr-bt* linkage group is not complete since tests for the presence of the second gamete factor were made only in a few cases. In stocks heterozygous for *bt*, *pr*, and ys_1, the F_2 data, given in Table 3, show deviations from 25% as follows: Minus 12.2% for *bt*, plus 13.0% for *pr*, and plus 4.8% for ys_1.

In the culture segregating only *bt* and *pr*, the deviations are minus 17.4% for *bt* and minus 10.1% for *pr*. Ears giving normal *bt* ratios also gave normal *pr* and ys_1 ratios. In the culture segregating *bt* and *pr*, the genes *bt-pr* entered from one parent and are both deficient, while in the other one the genes Ys_1, *Pr*, *bt* entered the cross from one parent and are the deficient ones. Since ys_1 shows the smallest deviation, it must be farthest from the differential gene, a result which is expected as linkage tests show the order to be *bt-pr-*ys_1. Based on the size of the deviation for *bt* and for *pr*, in this culture the gamete gene appears to be approximately equidistant between *bt* and *pr*, or slightly closer to *pr;* while in the other culture it appears to be much closer to *bt*. Previous evidence indicates that a second differential gene more closely linked with *pr* was also present in the culture segregating for ys_1, making the deviations for *pr* greater than if only the one closely linked with *bt* were present. Other tests to determine the closeness of linkage between *bt* and the gamete gene fall into three groups, the data being given in Table 4.

The data in group 1 of Table 4 may be used to calculate the percentage of crossing-over directly, as Emerson (1) has shown. The

TABLE 3.—*Table showing the relative deviations in F_2 ratios for bt, pr, and ys, and for bt and pr on ears giving low percentages of bt, and on those giving approximately normal percentages of bt.*

	No. of ears	*bt*			*pr*			*ys*		
		Total *bt*	Total grains	% *bt*	Total *pr*	Total grains	% *pr*	Total *ys*	Total grains	% *ys*
Culture 310 deficient in *bt*	8	253	1,980	12.8	526	1,385	38.0	341	1,143	29.8
Deviations from 25%				−12.2			+13.0			+4.8
Culture 310 approx. normal *bt* ratio	3	162	604	26.8	190	817	23.3	87	417	20.9
Deviations from 25%				+1.8			−1.7			−3.1
Culture 3935 deficient in *bt*	19	480	6,280	7.6	935	6,280	14.9			
Deviations				−17.4			−10.1			

TABLE 4.—*Distribution into low, normal, and high bt classes of selfed heterozygous ears from the self-pollinated and backcrossed descendants of ears giving low percentages of bt.*

	Number of ears				
	Low *bt*	Normal *bt*: Less than 22% but dev. not 3 x P. E.	Normal *bt*: 25%	High *bt*	Total
(1) Bt bt (X) from $\frac{\text{Bt Ga}}{\text{bt ga}}$ (x)*	179	7	8	1**	195
(2) Bt bt (X) from bt ga x $\frac{\text{Bt Ga}}{\text{bt ga}}$†	132	1	—	1	134
(3) Bt bt (X) from $\frac{\text{Bt Ga}}{\text{bt ga}}$ x bt ga‡	86	8	10	-	104
Total of (2) + (3)	218	9	10	1	238

*Self-pollination of *Bt* grains from low *bt* ears. Crossovers should give some with normal ratios, and others with high *bt* ratios.

**A progeny from this gave nothing but low *bt* ratios.

†Self-pollination of *Bt* from *bt ga* x $\frac{Bt\ Ga}{bt\ ga}$.

‡Self-pollination of *Bt* from $\frac{Bt\ Ga}{bt\ ga}$ x *bt ga*.

relative numbers in the three classes are not affected by the degree to which the *ga* gametes function in competition with *Ga* gametes. The one ear giving a high per cent of *bt* was tested and found to give nothing by low *bt*. If all 15 ears in the normal group are considered as crossovers, the percentage of crossing-over between *ga* and *bt* is 4; while if only the 8 ears which are closest to 25% are considered as normals, the value is 2%. In the last two groups of Table 4, the percentage of ears giving normal ratios should be the percentage of crossing-over between *bt* and the gamete gene. It will be noted that the reciprocal backcrosses indicated different amounts of crossing-over, less than 1% in one case and 17.3% in the other. The two groups are not strictly comparable, as the same heterozygous *bt* plants are not involved. Both gamete factors may have been present in part of the crosses and would account for the differences. The one high *bt* in group 2 is not expected from the hypothesis but may be a deviation from normal. In group 3, part of the ears showed less than 22% of *bt* grains, yet the deviation from 25% was not statistically significant. Undoubtedly many of these belong to the low *bt* class. Excluding all of these gives 9.6% crossing-over. The true value is probably somewhat higher than this.

As an additional check on the amount of crossing-over between *ga* and *bt*, and also to isolate a *bt* stock carrying the *Ga* allelomorph, crosses were made between normal *Bt* stocks and plants from the brittle grains on low *bt* ears. On such ears, if only the pollen carrying the differential gene which speeds up pollen tube growth can function, then all the *bt* seeds will be at least heterozygous for this gene. Owing to poor germination, only seven such *bt* plants were tested, only two of which gave progenies having ears with significant deviations. In one progeny one ear had a high percentage of *bt* grains (43.2). Another plant gave a progeny in which two out of four selfed ears had high ratios (32.4 and 30.1% *bt*). From the other five crosses, 17 ears were selfed, all of which had normal ratios. These last results are at least sufficient to indicate that *ga* gametes are not completely eliminated in the pollen. Further tests of the high *bt* ears indicated that the second gamete gene which is loosely linked with *bt* was involved. Thus far the author has been unable to isolate a *bt* stock which is carrying the Ga_3 factor which is closely linked with *bt*.

As to the ratio of *Ga* : *ga* presented for fertilization, information is given by the relative numbers of homozygous and heterozygous ears in this group 1 material of Table 4. There were 96 *Bt-Bt* : 135 *Bt-bt* ears; i. e., 41.7% were homozygous *Bt*. Assuming 4% of crossing-over between *Ga* and *bt*, a gametic ratio of about 2.8:1 would give these results. The data in Table 3 also bear on this same question. A table calculated by Mangelsdorf and Jones (5) gives the percentage of recessives expected for different combinations of recombination percentage and gametic ratios of *Ga* : *ga*. For the data involving *bt*, *pr*, and ys_1 simultaneously, the best fit between the known linkage values of these factors and the observed deviations is a gametic ratio of about 4.5 Ga : 1 ga with about 10% of crossing-over between *Ga* and *bt*, *Ga* being about equidistant between *pr* and *bt*. As pointed out previously, these data seem to be complicated by a second gamete

gene and therefore do not give the true value. In the Table 3 data, involving only *bt* and *pr*, the best fit is for a gametic ratio of 8 *Ga* : 1 *ga*, together with 5% of crossing-over between *ga* and *bt* and 24% between *ga* and *pr*. In this case the order would be: *ga-bt-pr*, and is different from that indicated in the ys_1 data.

In 1934 Jenkins (4) published backcross data for the linked genes a_2 and *bt* in which he calls attention to a deficiency of a_2 grains. Calculation of the percentage of *bt* grains in that material shows an excess of *bt*, the deviations from 50% being minus 5.9 for the a_2 and plus 4.6 for the *bt*. By calculating a table for backcross ratios produced by combinations of different percentages of crossing-over and different degrees of functioning of *ga* pollen, and using the method of Mangelsdorf and Jones, the best fit is with about 20% of crossing-over between *Ga* and a_2 and 26% between *Ga* and *bt;* the order being *Ga*-a_2-*bt*. This gamete gene appears to be loosely linked with *bt*, but located in the opposite direction from the second gamete gene in the author's material.

DISCUSSION AND SUMMARY

The data presented in this paper indicate that a gene closely linked to *bt* acts upon the pollen of heterozygous plants in such a way that relatively large deficiencies for one allelomorph result. The *Ga* allelomorph must either produce something which speeds up germination or growth of pollen tubes carrying this allelomorph, or something which retards those carrying *ga*. Evidence is presented that this gene must be considered as a dominant, and that it acts as a differential in the pollen only when the silks are carrying the gamete gene. The results from selfs and reciprocal backcrosses of plants heterozygous for *bt* and carrying the disturbing factor indicate that the deviations in the selfed ears are not due to the presence of a linked egg or pollen lethal. Examination of the pollen has shown that certain lines were partially sterile, but has indicated no relation to the deficient ratios.

Comparison of the ratios given by *Bt* non-crossovers and by *Bt* crossovers between the *pr* and *bt* loci indicates that a second such gamete gene may be present in certain stocks. The first gene, which we may designate as Ga_3, is closely linked with *bt*. The presence of a second gene was not suspected until late in the studies; consequently the linkage tests in certain cases involved both genes simultaneously. One of the genes (Ga_3) is closely linked with *bt*, but the data conflict as to the side of *bt* on which it is located. The second gene appears to be nearer to *pr*.

In the case described by Emerson (1), Ga_1 was relatively loosely linked with *su* (30.9% recombination), but only a small percentage of *ga* pollen was effective. In the case reported here, there is close linkage with *bt*, but ga_3 pollen functions to a much greater extent. In the latter case the ratios resulting from selfing heterozygous plants depend to a large extent on pollen-tube germination or growth. It is possible that variations in the environment may affect these processes, and thus account for some of the extreme variability in *bt* ratios. Part of the variation in certain lines, however, can be explained by the presence of at least two *Ga* factors in this linkage group. Different

combinations of these in coupling and repulsion would be expected to give a wide range of ratios.

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THE INFLUENCE OF SUPERPHOSPHATE AND LIGHT LIME APPLICATIONS ALONE AND IN COMBINATION ON THE COMPOSITION OF SWEET CLOVER[1]

H. E. MYERS AND W. H. METZGER[2]

DURING the past 5 years cooperative experiments were conducted on several soil types in eastern Kansas to determine the value of light lime applications with and without superphosphate on the yield of sweet clover.

Interest in mineral deficiency in livestock feeds grown in eastern Kansas, together with some variation in the results obtained by several investigators studying the effect of fertilizers on plant composition, led to the initiation of the project herein reported. Snider and Hein (5)[3] reported results showing the effect of soil treatment on the yield and total nitrogen, phosphorus, and potassium of sweet clover. A paper by Grizzard (2), reporting the results of a similar study with alfalfa, contains a brief review of the recent literature.

A. L. Clapp and F. L. Timmons, who conducted the field trials, harvested the samples from the sweet clover fertility tests and made them available for analysis. Samples have not been obtained since 1933 due largely to unfavorable climatic conditions. However, since the limited data show some interesting relationships, it was decided to present those now available even though more data are desirable. Samples were available from the following treatments: Untreated, ground limestone, treble superphosphate,[4] and trebel superphosphate plus ground limestone.[5] All treatments were applied through a fertilizer attachment on a drill equipped with a grass seeder attachment. This permitted the treatments to be applied in contact with the seed. The sweet clover seed was inoculated, but no observations were made to determine the effectiveness of the inoculation. Both first and second year cuttings were available from most of the successful tests. After harvesting, the samples were dried and the sweet clover separated from the weeds and trash before being ground in preparation for analysis. Total nitrogen, phosphorus, and calcium were determined.

EXPERIMENTAL METHODS

Nitrogen was determined by digesting the samples according to the Gunning-Hibbard procedure and distilling the ammonia into a boric acid solution, after which it was titrated directly by H_2SO_4 in the presence of brom cresol green-methyl red indicator. For phosphorus determination the first-year sweet clover samples were ashed in the presence of Mg $(NO_3)_2$. The second-year samples were

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[3]Figures in parenthesis refer to "Literature Cited", p. 984.

[4]80 pounds per acre drilled in the row.

[5]300 pounds drilled in the row.

ignited in the presence of $CaCO_3$ according to the method developed by Howk and DeTurk (3). Phosphorus was then determined by the standard volumetric procedure. Calcium was determined by the method developed by Chapman (1), in which the calcium is precipitated in the presence of iron, aluminum, titanium, manganese, magnesium, and phosphorus and the determination completed by the standard volumetric procedure.

RESULTS

The significant data are shown in Tables 1 and 2. From an inspection of the data it is quite evident that the variation in the nitrogen, phosphorus, and calcium content of the sweet clover grown in different counties was very marked. The location in which the samples were grown caused much greater variation in P and Ca content than did the applications of fertilizers.

EFFECT OF SOIL TREATMENT ON PERCENTAGE PHOSPHORUS IN THE PLANTS

The effect of superphosphate with and without lime on the percentage of phosphorus in the plant material was usually very small. In the first-year sweet clover samples the superphosphate treatment resulted in a slight increase in 5 of 7 comparisons, with a maximum increase of 0.034%. The greatest increases were under conditions where the yields were not favorably affected by the superphosphate treatment. Where the yield was increased 300 pounds or more per acre, the percentage phosphorus decreased in two instances (Saline and Riley) and increased very slightly in two cases (Nemaha and Linn). However, the maximum change was a 0.021% decrease in the Riley County sample.

Of the 10 second-year sweet clover samples, only 4 (Nemaha, Coffey, Jackson, and Washington counties) showed a change of 0.025% or more in phosphorus content as a result of superphosphate treatment. Of these four, the first three show increases and the last a decrease. Yield data are not available from the Nemaha County test, but from the first year results it appears probable that a difference in growth existed between the untreated and superphosphate plats. The Coffey County test showed a response, while those in Jackson and Washington counties showed no favorable influence from the phosphorus treatment.

The use of lime and superphosphate produced a somewhat variable effect on the percentage phosphorus. For the first year samples, five showed practically no change while two (Nemaha and Riley) showed probably significant lowering, 0.067% and 0.054%, respectively. Of the second-year samples, four (Nemaha, Washington, Coffey, and Douglas) showed increases and two (Saline and Linn) decreases, all of which are possibly significant. The remaining four showed changes which are probably of no significance.

The results from the Nemaha samples are interesting since lime and superphosphate resulted in a decrease in percentage phosphorus the first year and an increase the second year.

TABLE 1.—*The effect of soil treatment on the yield and composition of first-year sweet clover.*

Treatment	Yield, pounds per acre	Phosphorus*				Calcium†				Nitrogen		
		Percentage		Pounds removed per acre	Percentage recovery	Percentage		Pounds removed per acre	Percentage recovery	Percentage		Pounds removed per acre
		In plant	Difference			In plant	Difference			In plant	Difference	
Saline County												
Untreated	408	0.273	—	1.11	6.80	1.412	—	5.76	—	2.915	—	11.89
Phosphorus	824	0.259	−0.014	2.13	6.80	1.117	−0.295	9.20	34.4	2.571	−0.344	21.18
Lime and phosphorus	1,883	0.271	−0.002	5.10	20.46	1.491	+0.079	28.07	17.6	2.924	+0.009	55.05
Lime	1,214	0.167	−0.106	2.03	—	1.397	−0.015	16.96	10.37	2.674	−0.241	32.46
Nemaha County												
Untreated	645	0.193	—	1.24	—	1.456	—	9.39	—	2.494	—	16.09
Phosphorus	1,430	0.208	+0.015	2.97	11.53	1.097	−0.359	15.69	63.0	2.373	−0.121	33.93
Lime and phosphorus	3,054	0.139	−0.054	4.24	9.87	1.077	−0.379	32.89	15.9	2.124	−0.370	64.87
Lime	2,194	0.126	−0.067	2.76	—	1.092	−0.364	23.96	13.49	2.193	−0.301	48.11
Washington County												
Untreated	267	0.297	—	0.79	—	1.348	—	3.60	—	3.070	—	8.20
Phosphorus	248	0.324	+0.027	0.80	0.0	1.328	−0.020	3.29	0.0	2.760	−0.31	6.84
Lime and phosphorus	1,280	0.306	+0.009	3.92	0.0	1.319	−0.029	16.88	12.6	3.259	+0.189	41.72
Lime	2,071	0.255	−0.042	5.28	—	1.161	−0.187	24.04	18.93	3.053	−0.017	63.23
Cloud County												
Untreated	848	0.201	—	1.70	—	2.042	—	17.32	—	2.949	—	22.82
Phosphorus	591	0.222	+0.021	1.31	0.0	1.732	−0.310	10.24	0.0	2.820	−0.129	16.67
Lime and phosphorus	554	0.215	+0.014	1.19	0.80	2.037	−0.005	11.28	0.96	2.967	+0.018	16.44
Lime	541	0.197	−0.004	1.07	—	1.914	−0.128	10.35	0.0	2.691	−0.258	15.95

Miami County											
Untreated	161	0.138	—	0.22	—	0.984	—	1.58	—	1.943	—	3.13
Phosphorus	326	0.172	+0.034	0.58	2.40	1.014	+0.030	3.30	17.2	2.038	+0.095	6.64
Lime and phosphorus	1,920	0.140	+0.002	2.69	10.2	0.891	−0.093	17.11	12.8	1.909	−0.034	36.65
Lime	826	0.141	+0.003	1.16	—	1.048	+0.064	8.66	6.56	2.124	+0.181	17.54
Riley County												
Untreated	1,967	0.173	—	3.40	—	1.240	—	24.39	—	2.511	—	49.39
Phosphorus	2,409	0.152	−0.021	3.66	1.73	1.023	−0.217	24.64	2.5	2.442	−0.069	58.83
Lime and phosphorus	2,660	0.148	−0.025	3.94	9.26	1.038	−0.202	27.61	2.75	2.442	−0.069	64.96
Lime	2,142	0.119	−0.054	2.55	—	0.935	−0.305	20.03	0.0	2.347	−0.164	50.27
Linn County												
Untreated	603	0.150	—	0.90	—	1.796	—	10.83	—	2.279	—	13.74
Phosphorus	946	0.154	+0.004	1.46	3.73	1.624	−0.172	15.36	45.3	2.003	−0.276	18.95
Lime and phosphorus	1,084	0.145	−0.005	1.57	0.0	1.343	−0.453	14.56	0.0	2.072	−0.207	22.46
Lime	1,126	0.161	+0.011	1.81	—	1.353	−0.443	15.23	4.07	2.175	−0.104	24.49

*15 pounds applied per acre to phosphorus-treated plats.
†108 pounds applied per acre as calcium carbonate; 10 pounds as superphosphate.

TABLE 2.—*The effect of soil treatment on the yield and composition of second-year sweet clover.*

Treatment	Yield, pounds per acre	Phosphorus*				Calcium†				Nitrogen		
		Percentage		Pounds removed per acre	Percentage recovery	Percentage		Pounds removed per acre	Percentage recovery	Percentage		Pounds removed per acre
		In plant	Difference			In plant	Difference			In plant	Difference	
Saline County												
Untreated	1,294	0.228	—	2.95	—	1.61	—	20.8	—	2.614	—	33.8
Phosphorus	2,475	0.221	—0.007	5.47	16.8	1.34	—0.27	33.2	100.0	2.778	+0.164	68.7
Lime and phosphorus	2,830	0.187	—0.041	5.29	0.0	1.43	—0.18	40.5	6.75	2.805	+0.191	65.2
Lime	3,802	0.210	—0.018	7.98	—	1.07	—0.54	40.7	18.4	1.823	—0.791	69.3
Nemaha County												
Untreated	—	0.232	—	—	—	2.25	—	—	—	2.941	—	—
Phosphorus	—	0.303	+0.071	—	—	1.61	—0.64	—	—	2.941	0.0	—
Lime and phosphorus	—	0.359	+0.127	—	—	2.20	—0.05	—	—	3.053	+0.112	—
Lime	—	0.235	+0.003	—	—	1.95	—0.30	—	—	2.855	—0.086	—
Washington County												
Untreated	958	0.354	—	3.39	—	1.30	—	12.4	—	3.130	—	30.0
Phosphorus	319	0.329	—0.025	1.05	0.0	1.22	—0.08	3.9	0.0	2.683	—0.447	8.6
Lime and phosphorus	3,099	0.376	+0.022	11.65	16.2	1.32	+0.02	40.9	3.43	3.285	+0.155	101.8
Lime	2,500	0.369	+0.015	9.22	—	1.47	+0.17	36.7	22.5	3.216	+0.036	80.4
Cloud County												
Untreated	3,004	0.259	—	7.78	—	2.14	—	64.3	—	2.606	—	78.3
Phosphorus	2,858	0.256	—0.003	7.32	0.0	2.55	+0.41	72.9	86.0	2.782	+0.176	79.5
Lime and phosphorus	3,029	0.245	—0.014	7.42	7.0	2.55	+0.41	77.2	3.98	3.044	+0.438	92.2
Lime	2,925	0.218	—0.041	6.37	—	2.86	+0.72	83.6	17.9	2.554	—0.052	74.7
Miami County												
Untreated	156	0.344	—	0.54	—	1.32	—	2.1	—	3.393	—	5.3
Phosphorus	381	0.384	+0.010	1.34	5.3	1.36	+0.04	5.2	31.0	3.311	—0.082	12.6
Lime and phosphorus	1,960	0.333	—0.011	6.53	25.0	1.38	+0.06	27.0	20.2	3.431	+0.038	67.2
Lime	1,088	0.255	—0.089	2.77	—	1.37	+0.05	14.9	11.8	3.341	—0.952	36.3

Linn County												
Untreated	2,143	0.235	—	5.04	—	1.73	—	37.1	—	2.025	—	43.3
Phosphorus	3,135	0.232	—0.003	7.27	14.8	1.31	—0.41	41.1	40.0	2.318	+0.293	72.7
Lime and phosphorus	3,268	0.205	—0.030	6.70	0.0	1.40	—0.33	45.7	4.26	2.245	+0.22	73.4
Lime	3,600	0.198	—0.037	7.13	—	1.17	—0.56	42.1	4.6	1.875	—0.15	67.5
Coffey County												
Untreated	219	0.204	—	0.45	—	1.73	—	3.8	—	2.786	—	6.1
Phosphorus	1,347	0.230	+0.026	3.10	17.6	1.99	+0.026	26.8	100.0	2.692	—0.094	36.3
Lime and phosphorus	1,599	0.227	+0.023	3.63	18.2	1.96	+0.023	31.3	4.17	2.683	—0.103	43.9
Lime	464	0.194	—0.010	0.90	—	1.94	+0.021	9.0	4.8	2.632	—0.154	12.2
Jackson County												
Untreated	54	0.272	—	0.15	—	1.43	—	.8	—	2.950	—	15.9
Phosphorus	100	0.328	+0.056	0.33	1.12	1.68	+0.25	1.7	9.0	2.851	—0.099	28.5
Lime and phosphorus	746	0.271	—0.001	2.02	7.2	1.73	+0.30	12.9	10.37	2.374	—0.576	17.7
Lime	576	0.164	—0.108	0.94	—	1.77	+0.34	10.2	8.7	2.313	—0.637	13.3
Jefferson County												
Untreated	162	0.340	—	0.55	—	1.30	—	2.1	—	3.230	—	5.2
Phosphorus	388	0.342	+0.002	1.33	5.2	1.36	+0.06	5.3	32.0	3.302	+0.072	12.8
Lime and phosphorus	706	0.350	+0.010	2.47	0.0	1.32	+0.02	9.3	3.7	3.577	+0.347	25.3
Lime	1,313	0.315	—0.025	4.14	—	1.46	+0.16	19.2	15.8	3.388	+0.158	44.5
Douglas County												
Untreated	207	0.241	—	0.50	—	1.13	—	2.3	—	2.743	—	5.7
Phosphorus	330	0.247	+0.006	0.81	2.1	1.00	—0.13	3.3	10.0	2.687	—0.056	8.9
Lime and phosphorus	381	0.266	+0.025	1.01	0.2	0.99	—0.14	3.8	0.33	2.988	+0.245	11.4
Lime	356	0.272	+0.031	0.97	—	1.26	+0.13	4.5	2.0	2.623	—0.012	9.3

*15 pounds applied per acre to phosphorus-treated plats

†108 pounds applied per acre as calcium carbonate, 10 pounds as superphosphate

When the first-year sweet clover samples are considered, lime alone resulted in either no change or a material decrease in the percentage of phosphorus in the crop. The second-year samples show either little change or a marked decrease except for the Douglas County sample in which the percentage of phosphorus was increased. It should be noted, however, that the yield was not materially affected by the treatment in this county.

EFFECT OF SOIL TREATMENT ON THE PERCENTAGE OF CALCIUM IN THE PLANTS

In the first-year crop the superphosphate treatment caused a decrease in the percentage of calcium in all samples except the one from Miami County where a small, probably not significant, increase was found. In five of the seven samples the decreases varied from 0.172 to 0.359%. In the second-year crop the changes were not so consistent since half the samples showed a decrease and the other half an increase. However, in only one instance (Coffey County) was an increased percentage of calcium associated with a marked yield increase and in that case the increase of calcium was probably not significant (0.026%). In contrast, where large yield increases resulted from superphosphate treatment (Saline, Linn, and probably Nemaha), the percentage calcium decreased materially (0.27, 0.64, and 0.41%, respectively).

The lime and superphosphate treatment resulted in a decreased percentage of calcium in the first-year crop in all counties except in Saline where a small increase of 0.079% was found. The results were not as consistent for the second-year samples with half showing increases and the other half showing decreases in the percentage of calcium. However, in no case was a significant increase associated with a marked yield increase. On the other hand, significant yield increases tended to be associated with marked reductions in the percentage of calcium. Marked increase in percentage of calcium occurred only where the yield was low or the increase in yield was small.

Lime alone resulted, in general, in a significant reduction in the percentage of calcium in both the first- and second-year samples wherever its use produced a marked increase in yield. Second-year samples from Washington, Miami, and Jefferson counties are exceptions to this generalization. The yield in Miami and Jefferson counties on limed plats was very low.

EFFECT OF SOIL TREATMENT ON THE PERCENTAGE OF NITROGEN IN THE PLANTS

In the first-year samples superphosphate treatment resulted in a decreased percentage of nitrogen in the plants in all but one instance where a small, possibly not significant increase, was found. However, in the second-year samples this same treatment resulted in a decreased percentage of nitrogen in five instances, but only in the Washington sample was the decrease great (0.447%); otherwise the maximum decrease was 0.099%. Three samples showed increases varying from 0.164 to 0.293%.

The lime plus superphosphate treatments produced quite variable influences on the percentage of nitrogen. Of the first-year sweet clover samples, two showed probably significant decreases, one a significant increase, and four unimportant increases or decreases. In the second-year samples there was a tendency for this treatment to increase the percentage of nitrogen, which was true in 8 of the 10 comparisons. The Jackson County sample, however, showed a large reduction from this treatment.

Lime alone had a distinct tendency to reduce the percentage of nitrogen in both the first- and second-year samples. The only exceptions are one first-year and two second-year samples.

RECOVERY OF ADDED NUTRIENTS

The pounds of nutrients removed per acre and the percentage recovery of added phosphorus and calcium are also shown in Tables 1 and 2.

The efficiency with which phosphorus was used under conditions of this experiment varied. The addition of lime with the superphosphate in some cases increased and in other cases decreased the efficiency of the utilization of the added phosphorus. The same holds for the utilization of calcium, that is, superphosphate increased in some cases and decreased in others the efficiency with which the calcium was utilized. In general, the percentage recovery for phosphorus was of the order mentioned in a statement by Russell (4) to the effect that the recovery of an initial application of phosphorus in superphosphate has usually not exceeded 20%. On extremely phosphorus-deficient soils, phosphorus recovery would very probably be much greater than was the case in the work reported here. In a substantial majority of the tests, however, the total removal of phosphorus per acre was greater for the treated plats than for the untreated ones. The same was true of calcium removal.

SUMMARY

The data presented, although limited in scope, indicate rather conclusively that under conditions existing in eastern Kansas, the use of ordinary applications of superphosphate either alone or with a light application of lime did not consistently increase the percentage of phosphorus in sweet clover. Neither did the use of light lime applications increase the percentage calcium in the plants. The variation in composition of the sweet clover from the untreated plats in the different counties was greater than the variation in composition resulting from treatments in any one county.

There appears to be a tendency for large response from the application of phosphorus or calcium to be associated with a decreased percentage of the corresponding element in the plant, and little or no response appears to be associated with increased percentages of these elements.

Light applications of lime showed a marked tendency to reduce the percentage phosphorus and nitrogen in sweet clover.

Superphosphate treatment tended to produce a lower calcium percentage in the plant. The effect of this treatment on the nitrogen

of the crop was less consistent. The effect of superphosphate plus lime treatment was quite inconsistent in its influence on the percentage composition of all the elements considered.

The effect of treatment tended to be greater and more consistent in the first-year crop than in the second.

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A PRELIMINARY REPORT OF VARIETAL DIFFERENCES IN RAPIDITY OF GERMINATION IN RICE[1]

CHIEN-LIANG PAN[2]

SEVERAL years ago, the writer observed in the field that some varieties of rice germinated decidedly faster than others and those which emerged earlier usually gave a better stand later on. Unfortunately, no data were taken at that time; consequently, a special experiment was made in the spring of 1936 which was designed to determine whether varieties of rice are significantly different in rapidity of germination. The association of rapidity of germination with some other characters was also studied.

MATERIALS AND METHODS

Eighty-four varieties of the two groups of rice *Oryzae sativa japonica* and *O. sativa indica* were used in this experiment. According to the date of maturity, there were 29 early, 29 medium, and 26 late-maturing varieties. Among the 84 varieties, 24 were collected from farmers in different localities and the other 60 were selected from the breeding nursery.

The experiments were conducted by sowing the seeds in sand in flats in the greenhouse. Each flat was divided into 30 small squares with an area of approximately 2.2 by 2.5 inches. In each square, 25 seeds of a variety were sown and covered with sand to a uniform depth. Three replicates made a total of 75 seeds for each variety. The replicates were randomized.

The 24 farmers' varieties were sown on April 29, whereas the other 60 were sown on May 20. Three separate groups were made for the late plantings, making a total of four groups with one group of 24 varieties and three groups of 20 varieties in a group.

The data were taken by counting the number of seedlings that emerged each day. Finally, the average rapidity of germination was calculated for each variety. For instance, the 24 farmers' varieties were sown on April 20 and one seedling of variety A emerged on May 3, two on May 4, seven on May 5, eight on May 6, and five on May 7. The first seedling appeared 6 days after planting. The average number of days for germination was calculated by summing the products of 1x6, 2x7, 7x8, 8x9, and 5x10, and then dividing the total by 23, giving an average of 8.39 days.

The analysis of variance was used to determine whether there was a significant difference between varieties in rapidity of germination and χ^2 for independence was used to determine whether there was association between rapidity of germination with average date of maturity and also with the two groups of rice, *japonica* and *indica*.

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[2]Senior Agronomist. The writer wishes to express his appreciation to Dr. H. K. Hayes, Adviser of the Institute, for suggestions and criticisms in regard to the interpretation of data and the preparation of the manuscript. Thanks are also given to Mr. Y. C. Chu for his assistance in conducting the experiment.

EXPERIMENTAL RESULTS

VARIETAL DIFFERENCES IN RAPIDITY OF GERMINATION

Variation due to varieties was considerably greater than that of the experimental error showing that there is some difference in the rapidity of germination between varieties. As a matter of convenience the results of the analysis of variance for the four groups of test are presented in Table 1.

TABLE 1.—*Analysis of variance for rapidity of germination of the four groups.*

Variation due to	D/F	Sums of square	Variance	S. E.	F
		Group 1			
Blocks	2	.8889	.4444		
Varieties	23	45.6683	1.9856	.373	14.23
Error	46	6.4172	.1395		
Total	71	52.9744			
		Group 2			
Blocks	2	.2117	.1058		
Varieties	19	31.9045	1.6792		13.89
Error	38	4.4137	.1162	.341	
Total	59	36.5299			
		Group 3			
Blocks	2	.3611	.1806		
Varieties	19	34.7262	1.8277		13.89
Error	38	5.0009	.1316	.362	
Total	59	40.0882			
		Group 4			
Blocks	2	3.4604	1.7302		6.1771
Varieties	19	31.3947	1.6524		5.8993
Error	38	10.6445	.2801	.547	
Total	59	45.4996			

In all four studies the variance for varieties exceeded that for error and gave a P value greater than .05. In the first three groups the variance for blocks was small, while in the fourth test the variation for blocks was even greater than for varieties.

A generalized error for average days to germinate was calculated for each of the four groups as follows.

The standard error of a single determination for group 1 was .373 which when divided by the square root of 3, the number of replicates, and multiplied by the square root of 2, gave the mean standard error of a difference equal to .304. Standard errors were calculated also for the other three groups.

Within each group all possible differences were obtained between varieties and these differences were placed in classes according to whether they fell with 1 x S. E., 2 x S. E., i. e., between 1 x S. E. and

3 x S. E., etc. In group 1 with 24 varieties there were ½ (24 x 23), or 276 comparisons, while in each of the other three groups there were 190 comparisons. The results of these studies are given in Table 2.

TABLE 2.—*Number of differences between varieties falling in the groups 1×SE., 2×S.E., etc.*

Size of difference	Group 1		Group 2		Group 3		Group 4	
	No.	% difference	No.	% difference	No.	% difference	No.	% difference
1×S.E.	117	42.39	45	23.68	65	34.21	53	27.89
2×S.E.	40	14.49	32	16.84	32	16.84	56	29.47
3×S.E.	10	3.62	24	12.63	20	10.53	39	20.53
4×S.E.	21	7.61	22	11.58	14	7.37	28	14.74
5×S.E.	35	12.68	28	14.74	10	5.22	8	4.21
6×S.E.	22	7.97	23	12.10	14	7.37	6	3.16
7×S.E.	12	4.35	6	3.16	20	10.53		
	19	6.88	10	5.26	15	7.89		

It is apparent that some of the differences are very great. A further study will be made of the mode of inheritance of these differences by selecting varieties as parents that differ widely in average date of emergence.

ASSOCIATION OF RAPIDITY OF GERMINATION WITH *japonica* AND *indica*

There are two groups of rice, namely, *japonica* and *indica*. The former is round in seed shape and somewhat more susceptible to stem borer infestation, while the latter has seeds that are longer. Sterility usually occurs in the F_1 hybrid generation of the cross between *japonica* and *indica*, although both subspecies have 12 chromosomes in the haploid phase. From the results of such genetical study, the two groups seem distinctly different in nature. A study of association of the two groups with the rapidity of germination were made of data obtained from groups 2, 3, and 4. The results are presented in Table 3.

TABLE 3.—*Frequency table for average date of germination of varieties of japonica and indica rice.*

Groups	Classes for average days required for germination of rice varieties						Mean calculated
	8.3	8.8	9.3	9.8	10.3	10.8	
Indica....	5	15	6	6	5	3	9.3
Japonica	0	4	1	1	4	10	10.2

It is apparent that varieties of *japonica*, on the average, have a slower rate of germination than varieties of *indica*. The differences may be shown to be very significant by χ^2 for independence. These varieties are grouped in smaller classes for this study (Table 4).

TABLE 4.—*Contingency table for rapidity of germination of the two groups of rice, japonica and indica.*

Group	Classes for germination		
	8.3 to 8.8	9.3 to 9.8	10.3 to 10.8
Japonica	20	12	8
Indica	4	2	14
$\chi^2 = 14.3773$			

The χ^2 value obtained is much greater than the value for a P of .01, indicating that the observed number did not fit the calculated number.

ASSOCIATION OF RAPIDITY OF GERMINATION WITH DATE OF MATURITY

In rice varieties differ considerably from each other in the date of maturity. An association study was made also with the materials tested in the groups 2, 3, and 4. Most of the late-maturing varieties were *japonica* rice, consequently only the early, medium, and late-maturing varieties of *indica* rice were used in this study (Table 5).

TABLE 5.—*Frequency table for the rapidity of germination of the early, medium, and late-maturing varieties of indica rice.*

Group	Classes for the average days required for germination					
	8.3	8.8	9.3	9.8	10.3	Mean calculated
Early	3	8	3	3	7	9.4
Medium	1	6	2	2	0	9.0
Late	1	1	1	1	1	9.3

It is apparent that the average days required for germination of the early, medium, and late-maturing varieties were not significantly different.

It is interesting to analyse the data by putting those below 9.5 days into one group and those above into another group. The summary on this basis is given in Table 6.

TABLE 6.—*Frequency distribution with only two classes for the rapidity of germination of the early, medium, and late-maturing varieties.*

Group	Classes for the average days required for germination	
	Below 9.50	Above 9.50
Early	14	10
Medium	9	2
Late	3	2

A χ^2 test for independence was made to determine whether association of rapidity of germination occurred with date of maturity

within the varieties of *indica* rice. The P value was greater than .3, indicating no association. This means that there was no significant difference in rapidity of germination between varieties of different maturity of the *indica* rice. Only five late-maturing varieties were used in this experiment, however.

SUMMARY

1. A germination test was made of 84 varieties of rice. They were placed in four groups for studying the average days required for germination.

2. Number of days required for germination was found to be different with varieties.

3. The varieties belonging to the *indica* group germinate much faster on the average than those belonging to the *japonica* group.

4. Within the *indica* group there was no significant association between time of maturity and rapidity of germination.

A SECOND-CHROMOSOME GENE, Y_3, PRODUCING YELLOW ENDOSPERM COLOR IN MAIZE[1]

H. S. PERRY AND G. F. SPRAGUE[2]

CORRENS (1)[3] accounted for the inheritance of yellow endosperm color in maize on the basis of a single factor pair. Emerson (3) reported the linkage of a factor pair *Y*, *y*, (presumably the same as that of Correns) with *Pl pl*, genes which differentiate purple from sunred plant color. These genes are in the linkage group now designated as group 6 (4).

Other genes affecting endosperm color have been reported by East (2), Hayes and Brewbaker (6), and Eyster (5). The interrelations of these genes are unknown and all are now lost save Eyster's Y_2 which is reported in linkage group 5. As the gene reported in the present paper belongs in group 2, it is assumed to be different from Y_2 and is designated Y_3. The interrelations of Y_2 and Y_3 have not been studied. The interrelations of Y_1 and Y_3 will be discussed below.

In material segregating for Y_1y_1, the yellow endosperm color may vary from a deep orange to a lemon color. The term "yellow" is used to designate this entire range. The white segregates may vary from nearly pure white to pale lemon or cream. This slight coloration depends on factors other than y_1 and which usually do not interfere seriously with classification.

RELATION OF Y_3 TO Y_1

Crosses between white endosperm stocks of the genotype y_1y_1 and a certain other white endosperm stock produced only yellow F_1 seeds. In the F_2, segregations approximating 9 yellow to 7 white were obtained. This indicated the presence of a new factor similar in effect and complementary to Y_1. This hypothesis has been tested by making appropriate crosses, studying F_1, F_2, and F_3 breeding behavior and finally by locating the new gene Y_3y_3 in its appropriate chromosome group.

The F_2 data from crosses involving y_1 and y_3 are presented in Table 1. The results clearly indicate the presence of two factors conditioning the development of yellow pigment. Yellow seeds from these cultures were planted, the resulting plants selfed, and the F_3 progenies classified. The results are presented in summary form in Table 2, and are in complete agreement with the two-factor hypothesis.

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[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication September 3, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 996.

TABLE 1.—*Endosperm color segregations in 9 F_2 progenies from crosses involving y_1 and y_3.*

Progeny No.	Number of individuals			Dev./P.E. (9:7 ratio)
	Yellow	White	Total	
207-2	63	57	120	1.4
207-4	17	11	28	0.8
207-5	136	103	239	0.3
209-6	59	46	105	0.0
209-9	62	45	107	0.6
582-1	82	58	140	0.9
582-2	95	86	181	1.7
582-3	83	82	165	2.6
1343A-1	392	288	680	1.1
Total	989	776	1,765	0.27

TABLE 2.—*Summary of the F_3 progenies from yellow F_2 segregates listed in Table 1.*

Class	A	B	C
Ratio (yellow to white)	1:0	3:1	9:7
Number of families:			
Observed	9.0	31.0	25.0
Calculated	7.2	28.9	28.9
Values of Dev./P.E. for families:			
Number of values greater than 1	——	19.0	11.0
Number of values greater than 3	——	1.0	2.0
Greatest value	——	4.9	3.8
Total number of seeds	3,563.0	9,407.0	8,393.0
White seeds in per cent of total:			
Observed	0.00	24.79	44.69
Calculated	0.00	25.00	43.75
Dev./P.E.	——	0.77	2.58

The character albescent, *al*, which is closely associated with a factor for yellow endosperm color, was first reported by Phipps (9), who gave it the name "ghost" with the symbol *gh*. This character is very variable, but in most cultures the classification is satisfactory. Albescent seedlings range from complete albinos to greens with narrow transverse bands of white. The whitest of the seedlings usually die unless growth conditions are very favorable. The surviving plants may continue to exhibit transverse banding, or the chlorophyll content may diminish gradually, resulting in a light green or whitish appearance. In extreme cases the upper several leaves of the mature plant may be devoid of pigment. It was plants of this type that suggested the name "ghost" to Phipps. Albescent plants from late summer, fall, and early winter plantings seem to show a more marked deficiency of chlorophyll than plants from spring plantings. As a consequence, satisfactory classification can be made at an earlier stage.

A cross of $Y_1y_1Y_3Y_3$ A B Pl Al $\times$ $Y_1y_1y_3y_3$ A B pl al produced 42 yellow and 14 white seeds. A plant from one of the yellow seeds was selfed and the progeny (1343A-1, Table 1) were classified for the

characters yellow and white endosperm, purple and sunred plant color, and normal and albescent chlorophyll development. The indicated crossover values computed by the method of Immer (7) are as follows:

Y_1 — Pl	repulsion	.28
Y_3 — al	coupling	.01
Pl — al	coupling	.47 ± .02

The genes Pl and al exhibit linkage with endosperm color, Pl in the repulsion phase and al in the coupling phase. They are not linked with each other. Inasmuch as al and pl were introduced from the same parent, they could not show linkage in different phases with the same pair of genes. The fact that linkage in both coupling and repulsion is exhibited is further evidence of the presence of two factors conditioning yellow endosperm color.

F_3 progenies from yellow seeds heterozygous for only one factor for yellow endosperm (class B, Table 2) were used to establish tester stocks and to obtain further linkage information. Fourteen F_2 plants were thus tested, of which eight proved to be $\frac{Y_1\,pl}{y_1\,Pl}\ \frac{Y_3\,Al}{Y_3\,Al}$ and six $\frac{Y_1}{Y_1}\ \frac{Y_3\,Al}{y_3\,al}$ in constitution. Of the latter, two were segregating $Pl\ pl$. The six F_3 distributions which exhibit segregation for al are presented in Table 3. Field and greenhouse grown plantings are recorded separately. The distributions afford further evidence of close linkage between al and Y_3 and of the independence of these genes from Pl. The linkage data are in complete agreement with the supposition of a new endosperm factor, Y_3, by indicating (a) linkage between Y_1 and Pl, (b) independence of Y_3 and Pl, (c) close linkage of Y_3 and al, and (d) independence of al and Pl.

Of the 10 supposed crossovers between al and Y_3 (Table 3), 5 were tested and found to be non-crossovers. This may have resulted from mistaken endosperm classification or from hetero-fertilization (Sprague, 10). In additional backcrossed material in which hetero-fertilization was impossible, i. e., $Y_3y_3Alal \times y_3y_3alal$, no crossovers were observed. The data are as follows:

$Y_3\,Al$	$Y_3\,al$	$y_3\,Al$	$y_3\,al$
293	0	0	267

Some data indicating a higher frequency of crossing over in F_2 segregations are shown in Table 4. None of these supposed crossovers were tested. A stock is now available which is homozygous for yellow endosperm and albescent chlorophyll distribution. However, there is considerable evidence that yellow endosperm may be dependent on factors other than Y_1, Y_2, and Y_3, and since the mode of interaction is still unknown, the above stock cannot be considered as an adequately tested crossover.

TRISOMIC TESTS FOR CHROMOSOME ASSOCIATION OF Y_3 AND al

The method used to make trisomic tests is essentially that employed by McClintock and Hill (8). A plant trisomic for a known chromosome and heterozygous for the gene being tested is selfed. If

TABLE 3—F_3 segregations from F_2 plants of the genotype $Y_1Y_1Y_3y_3Alal$.

F_2 Ped. No.	Plant constitution	Greenhouse or field grown	Y_3				y_3				Crossover value		
			Al		al		Al		al		$Y_3\ Pl$	$Pl\ al$	$Y_3\ al$
			Pl	pl	Pl	pl	Pl	pl	Pl	pl			
1667A-1	$\frac{Y_1pl\ Y_1Al}{Y_1pl\ y_3al}$	Greenhouse	0	27	0	0	0	0	0	10			.00
		Field	0	32	0	0	0	0	0	3			
1667A-2	$\frac{Y_1pl\ Y_3Al}{Y_1pl\ y_3al}$	Greenhouse	0	28	0	0	0	1	0	7			.03
		Field	0	72	0	1	0	1	0	8			
1667A-3	$\frac{Y_1pl\ Y_3Al}{Y_1pl\ y_3al}$	Greenhouse	0	28	0	0	0	0	0	9			.00
		Field	0	34	0	0	0	0	0	6			
1667A-4	$\frac{Y_1Pl\ Y_3Al}{Y_1pl\ y_3al}$	Greenhouse	58	11	0	0	2	0	19	7	.42 or .58 ± .048	.40 or .60 ± .048	.00
		Field	50		0		1		8				
1667A-5	$\frac{Y_1Pl\ Y_3Al}{Y_1pl\ y_3al}$	Greenhouse	74	22	0	1	1	0	24	5	.44 or .56 ± .048	.48 or .52 ± .048	.05
		Field	61		0		1		8				
1667A-6	$\frac{Y_1Pl\ Y_3Al}{Y_1Pl\ y_3al}$	Greenhouse	32	0	0	0	0	0	12	0			.00
		Field	14	0	0	0	1	0	0	0			
Total. . .			543		2		8		126				.018

TABLE 4.—*Endosperm and chlorophyll color segregation in 4 F_2 progenies from the cross Al Y_3×al y_3.*

Progeny No.	Number of individuals of the phenotype indicated					Crossover value
	Al Y_3	*Al* y_3	*al* Y_3	*al* y_3	Total	
12064-1.....	205	3	21	67	296	.055
12064-2.....	190	12	17	60	279	.105
12064-3.....	78	1	10	25	114	.060
12064-4.....	250	16	20	73	359	.105
Total.....	723	32	68	225	1,048	.090

the gene is not associated with the chromosome for which the plant is trisomic, a normal 3:1 ratio will result. If it is associated with this chromosome, a trisomic ratio will result. A trisomic ratio (when the parent is of the type AAa) has a theoretical range from 35:1 (2.8% recessives) to 8:1 (11.1% recessives). The higher value represents a hypothetical case in which (a) the gene being tested is at the spindle-fiber locus, (b) the extra chromosome is never lost through mitotic irregularities, and (c) neither cells nor plants carrying the extra chromosome are handicapped. The lower value would occur in the hypothetical situation in which only monoploid spores are functional. Therefore an F_2 phenotypic ratio within these limits may be regarded as trisomic.

Since y_3 and *al* are closely linked, if not identical, either character could be used in trisomic tests. Albescent was chosen to avoid ambiguity arising from dihybrid segregation for endosperm color. Plants trisomic for a known chromosome were pollinated with pollen from an *al* stock. The resulting F_1 plants were selfed. A small sample of each F_2 progeny was grown to maturity for cytological examination of sporocytes, and the remainder of the progeny was grown for seedling counts. F_1 plants were checked genetically for the extra chromosome by means of genetic markers. The distributions to be given below include both mature plant and seedling fractions of each progeny. Data on survival are presented to show that differential viability had no significant effect on the results obtained.

Plants trisomic for chromosome 6 and homozygous for *Al* and the normal allelomorph, *Py*, the sixth chromosome gene for pigmy (4) were pollinated with *al py* pollen. The F_2 distributions from this cross are presented in Table 5. The data clearly indicate a trisomic segregation for *py* and a disomic segregation for *al*. Therefore, *al* is not in chromosome 6.

Plants trisomic for chromosome 2 and heterozygous for the second chromosome gene for liguleless leaf, lg_1 (either *Lg Lg lg* or *Lg lg lg*) were pollinated with pollen from an *al* stock. The F_2 distributions are given in Table 6. As indicated by the *Lg-lg* ratios, all F_1 plants listed were trisomic for chromosome 2, one (1711 B-1) being of the constitution *Lg lg lg* and four of the constitution, *Lg Lg lg*. Cytological examination showed the presence of the extra chromosome in plants of each progeny except that of 1713-2 in which no plants were examined. In this test, green and albescent plants do not occur in a

TABLE 5.—*Data on the F_2 progenies from 2 trisomic F_1 plants of the cross No. 6 trisome Al Py×al py.*

Progeny No.	Number of individuals of the phenotype indicated				No. seeds planted	No. plants classified	Ratio of classified to planted	Percentage of plants	
	Al Py	*Al py*	*al Py*	*al py*				*py*	*al*
1710A–1	158	13	48	2	232	221	0.95	6.8	22.6
1710B–5	190	14	55	4	311	263	0.85	6.8	22.4
Total....	348	27	103	6	543	484	0.89	6.8	22.5

3:1 ratio (Dev./P. E. = 15) but in the proportion of about 11:1. These results show that *al* and hence y_3 are in chromosome 2.

The positions of *al* and y_3 within the chromosome are still unknown. No *al lg* plants were found among the progenies of trisomic plants (Table 6). The F_2 from a diploid sib consisted of 101 *Al* Lg_1, 51 *Al* lg_1, 43 *al* Lg_1, and 0 *al* lg_1 plants. Five combined F_2 progenies from the cross y_3 x lg_1 consisted of 224 Y_3 Lg_1, 108 Y_3 lg_1, 99 y_3 Lg_1, and 2 y_3 lg_1 plants. These data are inadequate to place y_3 and *al* in relation to other genes of chromosome 2, but suggest that their loci are near that of lg_1.

TABLE 6.—*Data on the F_2 progenies from five trisomic F_1 plants of the cross No. 2 trisome Lg_1 lg_1 lg_1 or Lg_1 lg_1 lg_1×al.*

Progeny No.	Number of individuals of the phenotype indicated				No. seeds planted	No. plants classified	Ratio of classified to planted	Percentage of plants	
	Al Lg_1	*Al* lg_1	*al* Lg_1	*al* lg_1				lg_1	*al*
1711B–1	81	61	14	0	179	156	0.87	39.1	9.0
1712A–2	122	10	6	0	162	138	0.85	7.2	4.3
1712B–1	117	7	12	0	142	136	0.96	5.1	8.8
1713–2	101	14	8	0	149	123	0.83	9.4	5.4
1713–4	140	11	21	0	179	172	0.96	6.1	11.7
Total	561	103	61	0	811	725	0.894		8.4
Total minus progeny of 1711B-1	480	42	47	0	632	569	0.900	7.4	8.1

SUMMARY

Yellow endosperm coloration is dependent upon the interaction of the dominant allelomorphs of y_1 and y_3. Genetic tests indicate that Y_3 is closely linked with *al*, a chlorophyll deficiency type. By means of trisomic tests both *al* and y_3 are shown to belong in the second linkage group. The order of the genes is not indicated, but both *al* and y_3 are near lg_1.

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EFFECT OF GERMINATION AND SEED SIZE ON SORGHUM STANDS[1]

A. F. SWANSON AND ROBERT HUNTER[2]

ONE of the important steps in profitable sorghum production is that of securing stands. Stands may be altered by a number of factors a few of which are due to the peculiar characteristics of the seed. Other hazards to stands are a poor seedbed, low grade seed, planting too early, the use of improper planting plates, and torrential rains which may cover or wash away the young seedlings. Some of these hazards may be more easily controlled if the character of the seed is given consideration. The discrepancy between laboratory and field germination of seed of the better known sorghum varieties, as well as the influence of size of kernel on the number of plants per acre, are discussed in this paper.

LABORATORY AND FIELD GERMINATION COMPARED

Certain cultivated crops often show a much wider discrepancy between laboratory and field germination than is generally realized by many farmers. This discrepancy is probably greater for sorghum than for most crops. Experiments conducted at Amarillo, Tex., in 1914 and 1915 showed (5)[3] that five varieties of sorghum planted on April 1 in wet, cold soil resulted in field germination ranging from 11.4 to 33.0%. When the same varieties were planted on June 1 in moist soil when higher temperatures prevailed, the field germination ranged from 51.3 to 61.9%. Seed of good viability was used in the test, the laboratory germination being from 90 to 98.5%. It was concluded from the Amarillo data that "it is best to expect in field seedings of kafir, milo, and sorgo not more than 50 per cent of the laboratory germination and of feterita not over 40 per cent."

Engledow and Ramiah (1) in England found that under reasonably good planting conditions from 60 to 80% of the wheat sown may be expected to grow into plants to be harvested. Parasitic action, adverse weather, bad tilth, and bad seed (physiologically imperfect) were regarded as factors which may bring about very substantial reduction in the number of plants. These workers also found some varieties of wheat to be inherently poor and slow in germination as compared with other varieties.

Five varieties of wheat planted under optimum field conditions at Hays in 1935 germinated 83.0%. Under equally favorable planting conditions in June sorghums have averaged 60%.

[1]Contribution from the Fort Hays Branch of the Kansas Agricultural Experiment Station, Hays, Kans., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Contribution No. 21 from the Fort Hays Experiment Station. Received for publication September 4, 1936.

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[3]Figures in parenthesis refer to "Literature Cited", p. 1004.

Melchers and Brunson (3) secured 73.2, 81.1, and 71.1% field germination as averages from 63 farm samples of corn planted on April 17, May 7 to 12, and June 2, respectively, at Manhattan, Kans., in 1931. The average laboratory germination of all 63 samples was 91.4%. This represents an extreme case, as the weather at Manhattan was very unfavorable for corn germination in the spring of 1931. On the other hand, under favorable planting conditions at Hays in 1931, corn germinated 98% in the laboratory and 96% in the field. Under the same conditions 11 varieties of sorghum had an average germination of only 43% in the field and 88% in the laboratory.

In 312 field germination trials at Hays, covering a period of 3 years, only twice did any variety of sorghum germinate more than 90% and only six times above 80%. The average laboratory germination for the sorghums tested was 95%. The seed was all planted under reasonably favorable soil conditions. A frequency distribution of field germination is shown in Table 1.

TABLE 1.—*Frequency distribution of field germination of sorghum seed in 312 trials, Hays, Kans., 1932 to 1934, inclusive.*

Percentage range of field germination	Frequency
1 to 10	8
11 to 20	25
21 to 30	37
31 to 40	39
41 to 50	47
51 to 60	61
61 to 70	55
71 to 80	32
81 to 90	6
91 to 100	2
Total	312

Field germination studies with sorghum were undertaken at the Hays station for the 3-year period of 1932–34. Plantings were made on three dates each year. The seed, which was of high viability, was carefully graded and was planted in a well-prepared seedbed similar to that shown in Fig. 1. The seedbed was well supplied with moisture for all of the 1932 and 1933 plantings. Heavy rains that fell shortly after the May 15 and June 1 plantings in 1932 covered only a few plants. The soil was dry for some time in 1934 so that seeds planted on May 15, June 1, and June 15 emerged almost simultaneously.

The 3-year average laboratory and field germinations of 17 varieties of sorghum are compared in Table 2. The laboratory germination ranged from 89 to 98% with an average of 95%, whereas the field germination was only 45, 45, and 61%, respectively, for the May 15, June 1, and June 15 plantings with an average of 50% for all dates. Germination was considerably increased when the seed was planted on June 15 because of more favorable soil temperatures.

The germination among sorghum varieties differed considerably,

TABLE 2.—*Laboratory and field germination of sorghum seed, Hays, Kans., 1932 to 1934, inclusive.*

Variety	Number kernels per pound*	Percentage germination, 3-year average				
		Laboratory†	Field planted			
			May 15	June 1	June 15	All dates
Sorgo						
Black Amber	24,000	96	52	51	77	60
Leoti Red	27,745	94	46	40	59	48
Kansas Orange	20,640	96	63	61	72	65
Early Sumac	32,955	98	38	54	66	53
Average		96	50	52	69	57
Darso						
	16,490	96	48	51	71	57
Kafir						
Pink	24,690	95	47	41	63	50
Dawn	20,740	97	50	4	67	54
Western Blackhull	18,930	95	46	53	62	54
Average		96	48	46	64	53
Milo and Milo Hybrids						
Dwarf Yellow Milo	15,590	92	51	41	56	49
Beaver	14,170	89	31	36	52	40
Wheatland	16,475	92	52	47	59	53
Sooner	12,785	96	58	62	75	65
Kalo	21,765	95	43	45	63	50
Average		93	47	46	61	51
Soft-seeded Grain Sorghums						
Feterita	12,040	95	36	38	58	44
Wonder	18,730	97	43	50	52	48
Club	13,080	93	31	29	53	38
Hegari	17,925	95	26	21	33	27
Average		95	34	35	49	39
Grand average all groups		95	45	45	61	50

*Average two crop years 1932–33.
†Determined by the Kansas Seed Testing Laboratory, Manhattan, Kans.

being highest as a rule for the sorgos and darso and lowest for certain soft-seeded grain sorghums, including feterita, Club, and hegari.

SEED COAT A PROBABLE FACTOR IN GERMINATION

Microscopic examination of several varieties of sorghum seed made by Swanson (4) showed that the starchy mesocarp layer in the seed coat ranged from 10 to 30 microns in thickness in such varieties as Red Amber, darso, and Kansas Orange. This layer in kafirs ranged from 20 to 50 microns. In feterita and hegari the mesocarp was 70 to 80 microns in thickness.

FIG. 1.—Nosing out blank listed rows with a loose ground planter. The sorghum seed is dropped in a warm, mellow seedbed for quick germination.

Feterita is classed as a soft-seeded variety because of its thick mesocarp layer and chalky cuticle. When soaked for 2 hours feterita absorbed about 33% more water than kafir, which has a thinner layer and a more glossy cuticle. In cold, wet soil the seed of feterita often molds and rots and consequently fails to germinate. Better stands usually are obtained with the harder seeded varieties having a thin mesocarp.

INFLUENCE OF SIZE OF KERNEL ON STAND

Size of seed does not appear to be a varietal factor in germination from the standpoint of reserve food supply, as small-seeded sorghums show a tendency to germinate better than the large-seeded varieties. However, size of sorghum seed is of importance in the mechanical process of planting. Farmers frequently use planting plates with improper perforations or planter speeds and consequently obtain stands too thin or, more commonly, too thick for best yields.

The seed size of five representative sorghums are shown in Table 3 and Fig. 2. The seed of Early Sumac is among the smallest and that of feterita among the largest of the sorghum varieties. There were 31,628 kernels in a pound of Early Sumac, or about 2½ times as many as in feterita. The number of kernels for most varieties varies from 18,000 to 26,000 as indicated in Table 2. These wide ranges in kernel size can greatly modify the stands unless proper planting adjustments are made.

TABLE 3.—*Weight and size of seed of five varieties of sorghum.*

Variety	Number of kernels in 25 cc	Weight of 25 cc, grams	Number of kernels per pound	Volume per pound, cc	Size
Feterita	445	16.6	12,159	683.1	Large
Wheatland	662	18.3	16,408	619.7	Medium large
Western Blackhull kafir	728	18.1	18,243	626.5	Medium
Kalo	853	19.1	20,257	593.7	Medium small
Early Sumac sorgo	1,283	18.4	31,628	616.3	Small

The effect of size of holes in the planting plates on the pounds cf seed dropped and the calculated number of plants per acre are shown in Table 4. The planter was operated at medium speed with rows 42 inches apart. The number of feterita plants per acre varied from 8,421 to 30,932 and of Early Sumac from 61,016 to 144,773.

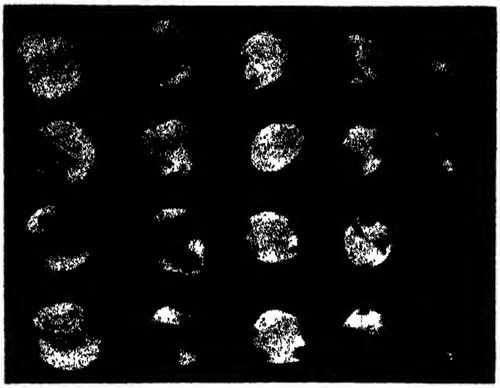

FIG. 2.—Relative size of sorghum seed. Left to right, feterita, milo, Western Blackhull kafir, Pink kafir, and Early Sumac (sorgo). Enlarged about twice.

Vinall, Getty, and Cron (5) reported that the actual row space

TABLE 4.—*Relation of perforations in planting plates to sorghum stands.*

	Number and diameter of holes in plates			
	32, 11/64 in.	32, 12/64 in.	32, 16/64 in.	32, 18/64 in.
Feterita*				
Pounds seed per acre	1.65	2.93	4.08	6.06
Kernels per acre	19,140	33,990	47,330	70,300
Plants per acre	8,421	14,956	20,825	30,932
Plant spacing, inches	17.7	10.0	7.2	4.8
Western Blackhull Kafir*				
Pounds seed per acre	3.11	3.95	5.73	7.45
Kernels per acre	65,930	83,740	121,480	157,940
Plants per acre	35,602	45,220	65,599	85,287
Plant spacing, inches	4.2	3.3	2.3	1.8
Early Sumac Sorgo*				
Pounds seed per acre	3.57	4.06	6.70	8.47
Kernels per acre	117,330	133,450	220,230	278,410
Plants per acre	61,016	69,394	114,520	144,773
Plant spacing, inches	2.4	2.2	1.3	1.0

*The field germination for feterita, kafir, and Early Sumac was 44, 54, and 52%, respectively. The plants per acre were calculated from these percentages.

for kafir at Chillicothe, Tex., ranged from 6.68 to 20.09 inches when plates having 6 to 12 holes 3/16th inch in diameter were used at slow and fast planter speeds. For Sumac the plant space varied from 4.81 to 10.76 inches. Kafir seeded at 1.5 to 2 pounds per acre resulted in a stand with approximately 9 inches of row space per plant and at 3 pounds gave a stand with about 7 inches of row space. With Sumac sorgo seed 1 pound gave a stand having approximately 11 inches of row space; 2 pounds, 9 inches; 3 pounds, 6 inches; and 4 pounds, 5 inches.

LOW VIABILITY AND FIELD GERMINATION

The data thus far presented were obtained from seed of high viability planted under favorable soil conditions. When the viability of the seed is low as a result of poor maturity, frost injury, or other causes, as frequently occurs in sorghums, the field germination is very uncertain.

It has been observed that when the laboratory germination is 85% or lower, a marked deficiency in field emergence may be expected. The difference between laboratory and field germination of frosted and poorly matured seed was determined from the 1933 crop. The results are shown in Table 5. The fall of 1933 was cold and rainy and the seed of most varieties was slow in maturing and drying. The seed was low in field germination even when collected before the approach of low temperatures.

TABLE 5.—*Laboratory and field germination of improperly matured and frosted sorghum seed, Hays, Kans., 1933.*

Variety	Percentage germination of seed collected from standing stalks					
	In October		On Nov. 28*		On Dec. 28†	
	Laboratory	Field	Laboratory	Field	Laboratory	Field
Western Blackhull kafir....	83	34	98	34	90	29
Dwarf Yellow Milo........	97	54	46	19	50	8
Dawn kafir....	97	27	93	17	76	9
Pink kafir.....	92	45	98	42	98	25
Kalo........	88	39	95	45	93	42
Feterita.......	96	61	27	17	21	4
Schrock.......	96	44	93	18	90	21
Average percentage...	93	43	79	27	74	20
Hays Golden corn......	92	47	52	25	—	—

*Temperature fell to −3° F on Nov. 22
†Temperature below 0° Dec. 19 to 20.

Zero temperatures in November and again in December reduced the average field germination for the varieties shown in Table 5 to 27 and 20%, respectively, as compared with 47% for the same seed

when harvested in October. In some cases frost-injured seed may show good laboratory germination and still respond poorly when field planted. On the other hand, partially immature seed, when not injured by frost, has been observed to give fairly satisfactory field germination when planted in a friable, mellow, moist soil with a temperature of approximately 75° F. A warm, moist soil of good tilth pressed firmly over the seed greatly aids germination and is one of the most important factors in successful stands. Martin, Taylor, and Leukel (2), in controlled greenhouse studies with sorghum seed of high viability, found that the best temperatures for germination ranged from 77° to 86° F and that the best planting depth was 1.5 inches.

Table 6 shows the field germination of several varieties of sorghum collected when in soft dough, fully ripe, and late in the season after exposure to frost and sleet, which encased the heads. The planting was done on June 1 in an excellent seedbed. High germination was obtained from soft dough seed as compared with the fully ripe seed, but delayed harvest and exposure to frost and sleet greatly reduced germination.

TABLE 6.—*Field germination of sorghum seed harvested in the soft dough stage, fully ripe, and 49 days after maturity at Hays, Kans., in 1931.*

Variety	Field germination in 1932 when seed was collected		
	Aug. 29, soft dough	Oct. 13, fully ripe	Dec. 1, after frost and sleet
Feterita	72	57	54
Dwarf Freed	80	56	—
Day Milo	76	82	28
Western Blackhull	69	80	—
Club Kafir	75	81	20
Wheatland	79	76	27

INFLUENCE OF CHEMICAL TREATMENT ON FIELD GERMINATION

Red amber, Dawn kafir, and feterita were treated at Hays with Coppercarb and mercurial compounds in 1927 and 1928. Coppercarb treatment gave an average increase in germination of 4.8% over the untreated seed. There was an average increase in germination ranging from 4.1 to 7.4% for the different mercurial compounds used.

No stimulation of vegetative vigor was noted in the seedlings or plants from the treated seed in comparison with those from untreated seed. The soft-seeded feterita responded to seed treatment most favorably in increased germination.

SUMMARY

The discrepancy between laboratory and field germination of sorghum seed frequently ranges from 30 to 50% even when seed

of high viability is used. When questionable seed is planted the field germination is very uncertain.

Seed of some sorghum varieties show inherently better ability to germinate under unfavorable planting conditions than seed from other varieties. This difference seems to be due in part to the relative thickness of a starchy layer of cells located in the seedcoat.

The number of kernels in a pound of sorghum seed varies approximately from 12,000 to 35,000, depending on the variety and somewhat on the plumpness of the seed. Because of this spread in seed size planting adjustments must be made to secure proper stands.

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THE OCCURRENCE OF STRIPED-LEAVED PLANTS FROM A CROSS BETWEEN TWO VARIETIES OF OATS[1]

H. H. Love and W. T. Craig[2]

CHLOROPHYLL deficiency does not seem to occur very frequently among the cultivated oat strains or hybrids between the different varieties or species. Robb (5)[3] reported results obtained from a cross between two normal-leaved cultivated varieties. In a second generation of 268 plants he obtained two with yellowish stripes on the leaves. Christie (3) had previously found a striped-leaved plant growing among plants sown from one variety, Moistad Grenadier. He grew some progenies from this material and found that there was considerable variation in the proportion of striped- and nonstriped-leaved plants in the different progenies. Akerman (1) has also reported on the occurrence of chlorophyll deficiency in oats. Coffman, Parker, and Quisenberry (4) also found striped-leaved and yellow plants in certain lines of the Burt oats. They did not study the behavior of this character in hybridization experiments.

As a result of a series of studies, Robb (5) states: "The results which I have obtained from the selfed progenies of the original striped-leaved plants found at Corstorphine agree in general with those obtained by Christie. The progenies of striped-leaved plants invariably consisted of a small proportion of apparently normal green plants and a much larger proportion of plants having striped leaves. The striping varied from plant to plant and frequently also on individual plants. On certain leaves there was only one narrow stripe, on others the stripes were more numerous, while in others again they were broader. Stripes have frequently appeared on the stems and sometimes the stripes could be traced along branches of the panicle on to some of the glumes. When the amount of green colour in the young leaves was markedly deficient the seedlings gradually withered and died after the development of the first or second leaf, but no plant devoid of green colour was observed. Various markedly striped-leaved types developed panicles and set some grain, but in most of those in which there was much striping on the leaves, the panicles and the amounts of grain produced were small. About eight generaations of striped-leaved plants have been grown, and amongst the progenies with striped leaves the amount of striping is still very variable. No fixed striped-leaved type has yet been isolated. Striped-leaved plants have produced apparently non-striped plants, and these in turn have produced only non-striped plants."

MATERIAL AND RESULTS

In the progeny of a cross between the variety Ruakura and a strain of *Avena sterilis macrocarpa*, the authors found some striped-leaved

[1]Paper No. 215, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Experiments were conducted in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication September 10, 1936.

[2]Professor of Plant Breeding, Cornell University, and Agent, Division of Cereal Crops and Diseases, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 1011.

plants occurring in the second generation. Both of the parents used in the cross had normal leaves and the F_1 plants resulting produced only normal green leaves. When the F_2 generation was grown, however, segregation for plant color occurred. There were 369 fully green plants obtained and 17 plants that showed various amounts of variegation. Such results might suggest a two-factor difference approaching the expected ratio of 15 : 1, the actual observed ratio being 21.7 : 1. Later results, however, show that the nature of the inheritance is not due to the chromosomes.

The striping varied from very narrow yellowish stripes to broad stripes. These striped plants were apparently very much like those described by Robb (5). The striping showed very definitely on the glumes as well as on the leaves and stems, and the glumes and leaves on the same plant varied greatly. The type of striping and the amount of variation is well illustrated in Fig. 1. The manner in which the stripes continue on the leaf sheaths and the glumes is shown in Fig. 2.

The effect of this chlorophyll disturbance on the development of the plants is such that the plants are smaller, and while they may tiller freely, the culms as a rule are not so well developed as in normal plants. The effect is also seen in the amount of seed developing. Some good seeds are produced by striped plants but not in great quantities.

From the F_2 material 157 green plants were selected for further testing. The seeds of 64 of these plants were grown in the greenhouse and the remainder were grown in the field. Of those grown in the greenhouse all but two produced normal green plants and these two families produced some variegated plants. Of the 93 F_2 plants that were tested in the field, 91 produced normal green plants and 2 segregated for plant color. Thus, of the total of 157 plants, 153 bred true for green color while 4 segregated for green and striped plants. Such results would not be expected if the inheritance depended on a two-factor difference, as suggested by the F_2 segregation. It seems that the behavior of the striped-leaved character is cytoplasmic rather than chromosomic.

The four plants that segregated for plant color gave the results shown in Table 1. It may be possible, though not necessarily the case, that these four F_2 green plants were really not green but may have shown very light striping and were incorrectly classified in the F_2 generation.

TABLE 1.—*Segregation for plant color in four F_3 families obtained from four normal green F_2 plants.*

Family	Number of green plants	Number of striped plants	Number of yellow or white plants
20	94	6	0
58	42	11	1
321	43	3	0
338	43	13	0
Total	222	33	1

The 17 variegated plants obtained in the second generation did not produce much seed, but the seeds available from each one were sown in the greenhouse and the resulting plants observed for striping. The results are shown in Table 2.

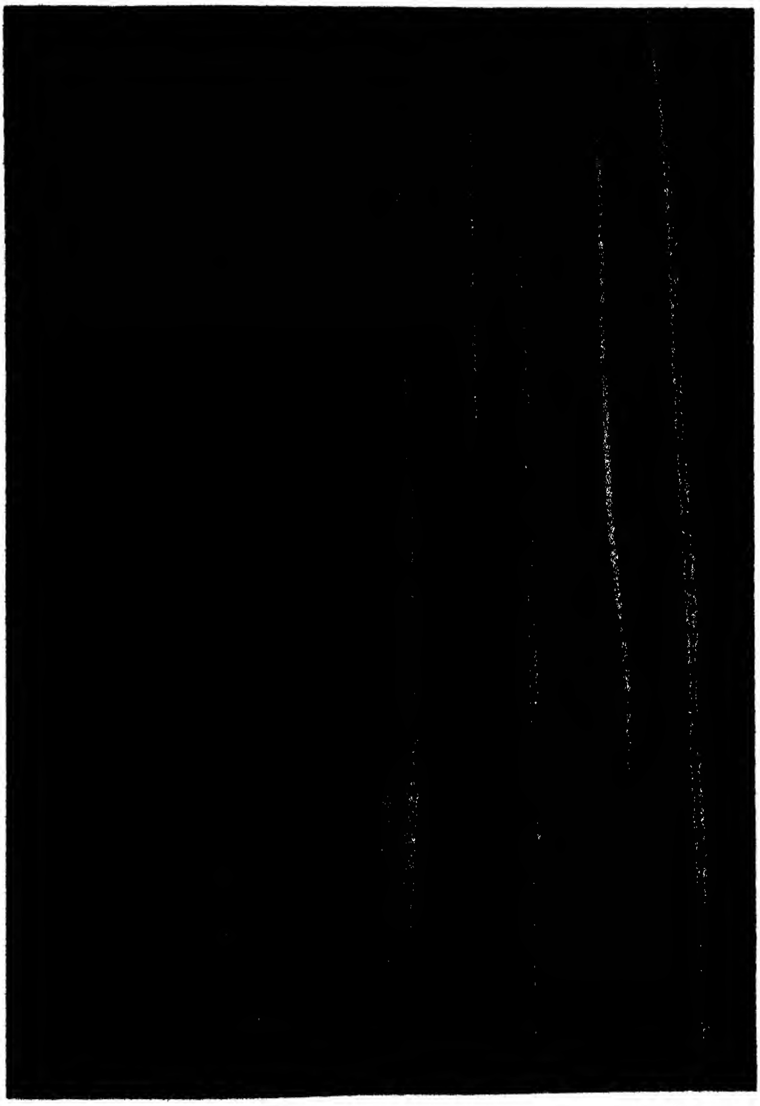

FIG. 1.—Showing variation in the amount and nature of striping.

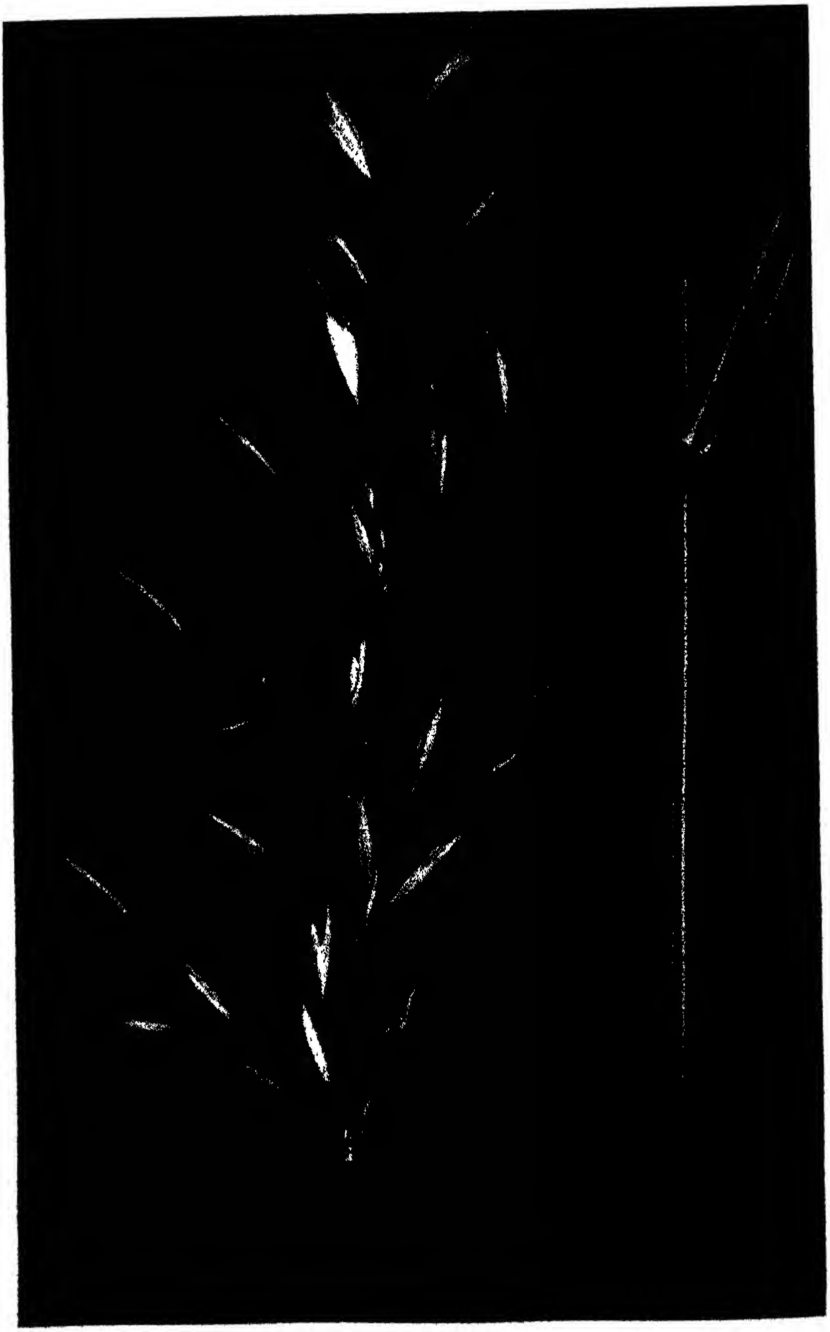

FIG. 2.—Showing the striping on stem, leaf, and glumes.

TABLE 2.—*Segregation obtained from the seeds of 17 variegated F_2 plants.*

Series No.	Number of green plants	Number of striped plants	Number of yellow or white plants
499a1–1	4	7	2
–2	5	3	0
–3	5	6	1
–4	6	6	2
–5	13	0	0
–6	6	6	0
–7	0	6	7
–8	7	5	0
–9	2	2	1
–10	0	4	2
–11	—*	—‡	—‡
–12	—†	—‡	—‡
–13	3	5	1
–14	2	4	2
–15	1	3	0
–16	3	6	3
–17	7	7	1
Total	64	70	22

*Only 1 seed.
†Only 2 seeds.
‡No plants developed.

No seedlings were obtained from the F_2 plants of series 11 and 12. The number of seedlings produced from the other plants was small and it is difficult from such small numbers to draw any definite conclusions as to the type of segregation.

The results for all of the plants showed 64 green-leaved: 70 striped-leaved: 22 yellow-leaved plants. The yellow or yellowish-white plants all died in the early seedling stage, but the striped plants developed fairly well. The striping in the leaves varied greatly from very fine to very broad stripes. Robb (5) did not report finding any yellow or white seedlings. All of his plants apparently developed some chlorophyll.

In order to obtain further information a number of crosses were made in which for one series variegated plants were used as the female parents and in the other series the fully-green plants were used as the female parents. A total of 49 F_1 plants was obtained when the flowers on the variegated plants were pollinated with pollen from those on the green plants. Of these 49 plants, 15 were either yellow or striped plants. When the flowers on the fully-green plants were pollinated with pollen from those on the variegated plants, a total of 26 F_1 plants were obtained and all of these were green.

Seeds were obtained from many of the plants and were sown for an F_2 generation. The results obtained from the first series, in which the variegated plants were used as females, are shown in Table 3.

In three cases, *viz.*, lines 2a1, 4a1, and 9a1, only entirely green plants were obtained. It might seem that the female parents used were not really variegated, but this was not the case. In line 8a1, in which the same female parent was used as in line 9a1, both variegated and yellow plants were obtained. The possible explanation of the all-green

TABLE 3.—*Results obtained in the F_2 generation from crosses between variegated (female) and green (male) plants from the cross Ruakura x Avena sterilis macrocarpa.*

Line	Number of green plants	Number of striped plants	Number of yellow or white plants
1a1	68	21	0
2a1	89	0	0
4a1	95	0	0
5a1	14	28	15
6a1	3	22	18
7a1	40	21	3
8a1	14	44	9
9a1	87	0	0
10a1	28	43	4
13a1	19	29	48
14a1	29	18	18
16a1	53	35	8
19a1	33	12	5
20a1	44	2	1
Total	616	275	129

plants is that the particular part of the female plant that produced the flowers for lines 2a1, 4a1, and 9a1 may have been all green. Since the variegation on the plants varied considerably, there were some flowers of the spikelets on the variegated plants that were all green. It is possible, then, that on certain plants the flowers used for crossing were not variegated but normal green. In this case it is possible to obtain all-green progeny from such crosses. In some of the crosses only green and striped plants were obtained, while in others yellow seedlings or plants completely lacking in chlorophyll were obtained.

From the crosses in which the normal green plants were used as the female parent a total of 13 lines were tested in the second generation. From these lines a total of 928 plants were produced and only green plants were obtained. These results suggest that the chlorophyll deficiency is cytoplasmic in nature. That is, in all cases in which the green plants were used as the female parents and the variegated as the male parents, no variegated plants were produced in either the F_1 or F_2 generation. On the other hand, when the reciprocal cross was made, variegated plants were obtained in both the F_1 and F_2 generations.

Some further studies were made in which spikelets showing various amounts of striping on the variegated plants were selected and seeds from these plants were grown in the greenhouse. It was difficult to make an accurate division as to the amount of green and striped areas, but approximate divisions were made. Of those spikelets that were about 90% yellow or yellowish, 26 plants were produced and 18 of these were yellow, a ratio of 1 yellow: 0.44 non-yellow. From seed from spikelets that showed about 25% yellow there were 63 plants that developed and 29 yellow plants were produced. This gives a ratio of 1 yellow: 1.17 non-yellow. From spikelets that showed only 10% yellow a total of 39 plants were obtained and 13 of these were

yellow. This gives a ratio of 1 yellow: 2.00 non-yellow. These numbers are too small to enable one to draw definite conclusions, but they do suggest a close relation between the amount of chlorophyll on the spikelet and the type of plant that will be obtained from the seed sown from these spikelets.

The foregoing results are very similar to those reported by Anderson (2) relative to a case of chlorophyll inheritance in maize, which was found to be cytoplasmic in nature.

SUMMARY

Data have been presented showing the behavior of striping as found in plants resulting from a cross between Ruakura and a strain of *Avena sterilis macrocarpa*. The occurrence of 17 striped plants out of a total of 386 plants in the second generation suggested an approach to a 15 : 1 ratio. Later results obtained from the F_3 generation proved that this was not the case.

Further results obtained from crosses in which the striped plants were pollinated with pollen from fully green plants and also in which the green plants were pollinated with pollen from the striped plants, showed that the behavior of the chlorophyll deficiency is not to be explained as due to the chromosomes but is apparently cytoplasmic in nature.

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THE EFFECT OF SULFUR AND SULFURIC ACID UPON THE DEVELOPMENT OF SOIL ACIDITY AT DIFFERENT DEPTHS[1]

G. S. Fraps and J. F. Fudge[2]

In connection with a study of the effect of acidity upon the cotton root-rot fungus, conducted in cooperation with Dr. J. J. Taubenhaus of the Division of Plant Pathology and Physiology of the Texas Agricultural Experiment Station, large quantities of several types of Texas soils were made acid either by sulfuric acid or by the oxidation of sulfur added to the soil.[3] The acidity of the soils, under field conditions, decreased in the course of time and almost disappeared after a few years. This decrease in acidity may have been partly due to the downward movement of acid caused by rain and partly due to the production of basic substances by the action of the acid or of weathering agencies upon the soil. The rate and extent of downward movement of soil acidity is of significance in connection with studies of the acidification of the soil in an attempt to control cotton root-rot. In order to ascertain the cause and extent of this decrease in acidity, and of the downward movement of soil acidity, the detailed experiments here reported were made.

EXPERIMENTAL

The surface soil of a Lufkin fine sandy loam was placed in 18 glazed tiles about 18 inches in diameter and 24 inches in depth, sunk in the ground to a depth of 19 inches. The buffer capacity of the soil was first determined by the method of Fraps and Fudge.[4] Sulfuric acid or sulfur were added to the top 5 inches of the soil in various multiples of the buffer capacity. Three tiles were used for each application.

Sulfuric acid sufficient to change the pH from 6.7, the pH of the untreated soil, to pH 4.5 (640 p.p.m. of sulfur) was added to the three tiles of series 1. Series 2 received 1.75 times this amount. In the sulfur applications, an allowance of 0.3 pH (to pH 4.2) was made for incomplete oxidation. Sulfur required for 1.50, 2.60, 3.75, and 7.50 times the quantity needed to reduce the pH to 4.2 was added to series 3, 4, 5, and 6, respectively. The additions were thoroughly mixed with the 70 pounds of soil in the top 5 inches on April 2, 1930. At various intervals during 5 years samples were taken with a fertilizer sampler. The top layer was sampled to a depth of 5 inches, but the other layers sampled were 1 inch. Each boring was made according to a diagram and was far enough from previous borings to prevent errors due to mixing or washing of the top soil through the hole into the lower layers. The pH was determined with the use of a quinhydrone electrode. The results, average of three cylinders, are presented in Table 1.

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Tex. Received for publication September 17, 1936.

[2]Chief of Division and Associate Chemist, respectively.

[3]Ezekiel, Walter N., Taubenhaus, J. J., and Carlyle, E. C. Soil-reaction effects on Phymatotrichum root-rot. Phytopath., 20:803–815. 1930.

[4]Fraps, G. S., and Fudge, J. F. Relations of buffer capacity for acids to basicity and exchangeable bases of the soil. Texas Agr. Exp. Sta. Bul. 442. 1932.

TABLE 1.—*Changes in the pH of acidified soils.*

Depth, inches	Months								
	2.4	4	6	13	23	32	48	55	61
Series 1. Sulfuric Acid, 1.00									
0–5	4.9	5.0	5.0	5.5	5.8	6.0	5.7	6.8	6.3
5–6	5.0	5.4	5.5	5.9	6.0	6.2	6.2	7.0	—
6–7	5.6	5.6	6.5	6.1	6.4	6.6	6.2	7.0	—
7–8	6.8	6.2	6.6	6.7	6.7	6.8	6.8	7.1	—
Series 2. Sulfuric Acid. 1.75									
0–5	4.2	4.2	4.5	4.6	4.9	5.5	5.0	5.9	5.4
5–6	4.8	4.4	4.8	5.2	5.3	5.5	5.6	6.3	—
6–7	6.2	5.5	5.3	5.8	6.0	5.9	5.8	6.4	—
7–8	6.4	5.9	6.4	6.3	6.3	6.4	6.2	6.5	—
Series 3. Sulfur, 1.50									
0–5	4.5	4.5	4.5	5.1	5.5	5.8	5.3	5.9	5.7
5–6	6.7	4.6	4.7	5.4	5.7	6.0	5.9	6.2	—
6–7	6.9	4.4	5.1	5.7	5.9	6.2	6.3	6.3	—
7–8	7.1	6.1	6.8	6.4	6.0	6.5	6.6	6.5	—
Series 4. Sulfur, 2.62									
0–5	3.7	3.7	3.9	4.5	4.8	5.3	4.7	5.2	5.0
5–6	4.3	3.0	4.6	4.9	5.2	5.6	5.1	5.5	—
6–7	6.3	4.8	6.1	5.6	5.6	5.7	5.6	5.8	—
7–8	6.8	5.9	6.8	6.8	6.1	5.9	5.8	6.1	—
8–9	—	6.5	7.0	6.8	6.6	6.2	6.3	6.2	—
9–10	—	—	—	7.0	7.0	6.9	6.4	6.4	—
Series 5. Sulfur, 3.75									
0–5	2.9	3.0	3.1	3.4	3.9	4.2	4.1	4.7	4.4
5–6	3.5	3.1	3.4	3.8	4.3	4.8	4.4	5.1	—
6–7	5.7	3.3	3.7	4.2	4.5	5.2	4.9	5.2	—
7–8	6.8	4.4	4.4	4.5	5.0	6.2	5.7	4.5	—
8–9	—	5.6	5.8	5.0	5.1	6.4	5.8	5.6	—
9–10	—	—	—	6.0	5.4	6.7	6.2	5.7	—
10–11	—	—	—	—	5.7	6.6	6.6	6.0	—
Series 6. Sulfur, 7.50									
0–5	2.8	2.2	2.5	3.0	3.4	3.7	3.7	4.6	4.0
5–6	2.9	2.4	2.9	3.3	3.5	3.8	4.2	4.6	—
6–7	4.1	2.7	3.0	3.4	3.4	3.7	4.0	4.6	—
7–8	6.8	3.2	2.9	3.6	3.5	3.9	4.1	4.5	—
8–9	—	3.9	3.5	3.7	3.6	3.9	4.1	4.6	—
9–10	—	—	—	4.0	3.7	4.0	4.2	4.6	—
10–11	—	—	—	—	3.7	4.0	4.2	4.8	—
11–12	—	—	—	—	3.8	4.1	4.3	5.0	—
12–13	—	—	—	—	3.9	4.4	4.3	5.4	—
13–14	—	—	—	—	4.4	4.5	4.4	5.5	—
14–15	—	—	—	—	5.0	4.6	4.5	5.5	—
15–16	—	—	—	—	—	4.7	4.8	5.4	—

CHANGES IN ACIDITY

The first samples were taken 10 weeks after the beginning of the experiment and at that time the acidity had reached its maximum in the top 5 inches of the surface soil with all the cylinders except

the one receiving sulfur equal to 7.5 times the buffer capacity. In this series the maximum was reached at the next sampling, which was made 4 months from the beginning of the experiment. After reaching the maximum, the acidity of the surface soil remained the same or increased slightly during the period before the next sample was taken. The acidity then slowly decreased.

The acidity had penetrated into the inch below the surface 5 inches at the time the first sample was taken, 10 weeks after the beginning of the experiment. The maximum acidity in this layer was found at the end of 10 weeks with the soils receiving the smallest quantity of acid and at the end of 4 months with all the other soils. It then began to decrease.

The acidity of the second inch below the surface 5 inches reached the maximum in 10 weeks with the soil receiving the lowest amount of acid-forming material and reached the maximum at the end of 4 months with the other applications.

The depth to which the acidity penetrated depended upon the quantity of acid or sulfur applied. With the smallest quantity the penetration did not exceed 3 inches below the surface 5 inches, while with the largest amount the acidity penetrated to a depth of more than 16 inches.

At the end of 5 years all the soils were considerably less acid than at the beginning of the sampling. The degree of acidity increased with the quantity of acid or sulfur applied. The rate of penetration was low.

The pH of the hydrogen-saturated soil was 3.9. An acidity below this occurred in some of the samples from series 4, 5, and 6. A pH of 2.2 was reached with series 6 in which 7.5 B sulfur was added. These acidities lower than 3.9 indicate that free sulfuric acid was present. This free sulfuric acid no doubt was washed down into the soil by rain and caused the subsoil to become more acid.

The subsoil also became more acid below layers having an acidity of less than 3.9 pH. It is thus possible that some of the acid surface soil was washed down into the layers below. Another explanation of the movement of the soil acidity is related to the salt effect of the soil. Soils become more acid when soluble salts are added to them and less acid when these salts are washed out. The increase in acidity may be due to the formation of free acids which are washed into the lower layers of the soil during rainy periods, thereby making it more acid. During dry periods, the salts may rise into the upper layers.

In order to acidify a subsoil by means of surface applications of acid or sulfur, it would be necessary to add such large quantities that the surface soil would be unsuitable for the growth of crops. As pointed out by Reynolds,[5] acidifying soils high in lime by the use of sulfur is not a practical method for the control of cotton root-rot. Acidifying a subsoil by single applications of acid for the purpose of controlling plant diseases therefore hardly seems to be a practical method.

Samples of soil taken at the end of the experiment had a higher

[5]REYNOLDS, E. B. The effects of sulphur on yields of certain crops. Texas Agr. Exp. Sta. Bul. 408. 1930.

pH after the soil was washed and a lower pH than the original soil when the estimation was made in normal potassium chloride. It is probable therefore that some of the variations in acidity shown in Table 1 were due to the salt effect, caused by the washing down of the salts in the soil by rain and to the rise of salts during dry weather. As shown by the analysis a sufficient quantity of salt was present in the soil to affect the pH of the soil, so that the pH was higher when the salt was washed out.

CHEMICAL EXAMINATION OF THE ACIDIFIED SOILS

At the end of the 61 months the soil was removed from the cylinders in three layers, each 5 inches thick. The corresponding layers from the three cylinders were mixed together. The results of analyses of these samples are given in Table 2. The pH of these layers has already been discussed.

TABLE 2.—*Effect of acidification after 61 months.*

Series No.	pH			Total exchange capacity, M. E.	Exchangeable hydrogen	
	As taken	Washed soil	With potassium chloride		M. E.	Per cent
			0–5 Inches			
1	6.3	7.0	5.7	13.75	4.53	32.9
2	5.4	5.9	4.6	11.44	4.50	39.3
3	5.7	6.2	4.7	12.88	4.29	33.3
4	5.0	5.5	4.1	12.07	6.01	49.9
5	4.4	4.8	3.5	11.76	8.23	70.0
6	4.0	4.3	3.2	10.39	9.63	92.7
			5–10 Inches			
1	6.4	6.9	5.6	14.59	1.79	12.3
2	6.4	6.8	5.4	13.43	2.48	18.5
3	6.6	7.0	5.6	15.46	2.55	16.5
4	6.2	6.4	5.2	13.08	3.16	24.2
5	5.9	6.3	4.8	13.46	4.02	29.9
6	4.1	4.4	3.5	11.76	10.32	87.8
			10–15 Inches			
1	6.8	7.1	5.8	13.60	1.63	12.0
2	6.8	7.2	5.8	13.27	1.74	13.1
3	7.1	7.5	6.0	15.01	1.73	11.5
4	7.2	7.4	6.1	14.22	1.38	9.7
5	7.0	7.5	6.1	13.69	1.19	8.7
6	4.9	5.4	4.1	12.68	5.84	46.1

The original soils contained probably 1.5 mg of hydrogen which was 12% of the total exchange capacity. As seen in Table 2, the exchangeable hydrogen was increased in all soils which had received the additions of sulfuric acid or sulfur. The increase was greatest in the surface soils and in the soils which received the highest quantity of sulfur.

The quantity of exchangeable hydrogen found was compared with the quantity which should be produced by the acid added or the sulfur added, assuming that sulfur was completely oxidized to sulfuric

acid. The quantity of acidity found was 86% of that added to series 1, 62% with series 3, 61% with series 4, 47% with series 5, and 50% with series 6. The percentage of the acidity found was too low for series 6, for the reason that some of the acidity had passed below the deepest layer of soil subjected to analysis. The percentage of acidity found decreased as the quantity of acidifying agent increased. On an average, 60% of the acid added was recovered as exchangeable hydrogen at the end of the 61 months. The loss of acidity varied from 14% to 53% of the quantity which should have been present.

This loss of acidity may have been due partly to action of the acid upon bases of the soil other than those in the exchange complex. It may have also been due to weathering of the soil with the production of bases. Since the loss of acidity was greatest with the soil receiving the most acid, it would appear that the acid had more effect than the weathering.

SUMMARY AND CONCLUSIONS

Different quantities of sulfuric acid and sulfur were added to the surface 5 inches of a Lufkin fine sandy loam in 18-inch tiles, and the pH values of samples of the soils from different depths were determined at intervals over a 5-year period.

Maximum acidity of the surface soil developed within 10 weeks and that of the next 2 or 3 inches within 4 months after treatment. Acidity of all treated soils then slowly decreased.

Penetration of acidity in excess of 2 or 3 inches occurred only in series in which the surface soil became so acid that no plant growth could occur. The presence of free sulfuric acid and soluble salts in the soil solution was evident from the pH values secured.

Increases in exchangeable hydrogen at the end of 5 years were equivalent to an average of about 60% of the acid added. The remainder of the acid must have reacted with non-exchange compounds in the soil, including bases made available by weathering.

Single applications of acid to the surface soil is not a practical method for acidifying the subsoil for the control of plant diseases.

REGISTRATION OF IMPROVED WHEAT VARIETIES, X[1]

J. ALLEN CLARK[2]

NINE previous reports present the registration of 51 improved varieties of wheat. In 1935, three varieties were registered, and as in former years, the previous registration was referred to.[3]

Two varieties approved for registration in 1936 are as follows:

Varietal Name	Reg. No.
Ramona	317
Erect	318

RAMONA, REG. NO. 317

Ramona (Calif. 537, C. I. No. 8241) was developed in cooperative experiments of the California Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. It is the result of a cross between Hard Federation and Bunyip made by W. W. Mackie in 1917. Dr. G. A. Wiebe applied for its registration.

Ramona is an awnless, short, early spring wheat with dark brown glumes and white kernels. It is a high-yielding variety and was first distributed for commercial growing by the California Experiment Station in 1935. The new variety has been under tests in experiments at Davis for 10 years. The comparative data upon which registration is based are shown in Table 1.

TABLE 1.—*Comparative yields of Ramona and other standard white spring wheats grown in plat experiments (five replications) at Davis, Calif., 1931–35.*

Variety	Yield in bushels per acre						Percentage of Baart
	1931	1932	1933	1934	1935	Av.	
Ramona (new)	36.6	80.2	42.8	53.3	72.4	57.1	114.7
White Federation (standard)	29.3	76.7	41.4	44.2	62.3	50.8	102.0
Baart (standard)	30.5	76.8	48.8	37.7	55.1	49.8	100.0

ERECT, REG. NO. 318

Erect (Utah Q-231, C. I. No. 11544) was produced at the Utah Agricultural Experiment Station in cooperative experiments with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, from a cross between Dicklow and Hard Feder-

[1]Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 19, 1936.

[2]Senior Agronomist, Wheat Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1936 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, IX. Jour. Amer. Soc. Agron., 28:66–68. 1936.

ation. The cross was made in 1920 and the selection from which Erect descended was made in 1930. The breeders, D. C. Tingey and R. W. Woodward, applied for its registration.

Erect is a soft white spring wheat. It has strong erect straw, is extremely uniform and high yielding, and has good quality of soft white grain. Seed was first distributed for commercial growing in 1934. Some of the comparative data upon which registration is based are shown in Table 2.

TABLE 2.—*Comparative yields of Erect and other standard white spring wheats grown in nursery and plat experiments in Utah, 1932–36.*

Variety	Yield in bushels per acre						Percentage of Baart
	1932	1933	1934	1935	1936	Av.	
Nursery, Logan							
Erect	55.4	61.5	78.6	75.3	68.2	67.8	104.5
Dicklow	54.1	61.5	73.1	64.2	76.0	65.8	101.4
Federation	56.5	50.9	80.1	67.4	69.8	64.9	100.0
Plat Experiments, Logan							
Erect	—	53.0	84.7	82.3	—*	73.3	104.3
Dicklow	—	51.8	79.4	78.9	—	70.0	99.6
Federation	—	55.3	86.6	69.1	—	70.3	100.0
Uniform County Nurseries							
Erect	—	—	67.0	72.4	63.0	67.5	104.2
Dicklow	—	—	60.2	68.9	63.5	64.2	99.1
Federation	—	—	62.8	68.6	63.0	64.8	100.0

*The test was conducted on land recently rented, and the soil was so variable that the test was not reliable.

Additional data were presented on lodging, date of heading, height, test weight, protein content, carotene and ash content, milling, bread and cake making, and cooky tests. These data were favorable for Erect, indicating superior characters for strength of straw and for pastry flour.

REGISTRATION OF IMPROVED COTTON VARIETIES, I[1]

H. B. Brown[2]

THE following cotton varieties have been registered as improved varieties and assigned registration numbers as follows:

Variety	Reg. No.
Deltapine	32
Ambassador	33
Washington	34

DELTAPINE, REG. NO. 32

Deltapine, formerly known as D. & P. L. 11 and D. & P. L. 11A, originated as a plant selection from a hybrid between an unnamed non-commercial hybrid and D. & P. L. 10. The cross was made in 1926 at Scott, Miss., by E. C. Ewing, in the cotton breeding program of the Delta and Pine Land Company. An F_2 selection was made in 1928, grown as a progeny row selection in 1929, and further selected in that year. From one of these selections, D. & P. L. 11 was developed. The variety was first put into an increase block in 1930, and has since been widely tested.

Plants of medium height, fairly open, stems and branches rather slender, mostly nearly glabrous and reddish in color; vegetative branches not extensively developed; leaves medium sized, usually dark green, and only slightly hairy. Flowers medium sized, cream colored; anthers cream colored, pistil but slightly longer than brush of anthers, if any; bracts rather large and deeply toothed; bolls medium sized, rather short pointed, fairly stormproof, locks holding in well but easily picked; length of staple $1\frac{1}{32}$ to 1 3/32 inches, usually $1\frac{1}{16}$; seeds quite small, brownish gray; lint percentage high, 37 to 42%, usually 38 to 40%; resistance to wilt and boll rots only fair; early. The record of the variety shows a high degree of productiveness. Its most distinctive feature is the unusual combination of very high lint percentage with good length of staple.

AMBASSADOR, REG. NO. 33

Ambassador, formerly known as Stoneville-4, was bred by C. A. Tate of the Stoneville Pedigreed Seed Company, Stoneville, Miss. The original selection, made by H. B. Brown, came from Lone Star-65, and was made in 1923 at Stoneville, Miss. Later selections purified the strain and increased its stability. The variety is now grown in Mississippi, southeast Missouri, northeast Arkansas, Texas, and Arizona, and also in China. It is adapted to regions of moderate rainfall and medium soil fertility.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 19, 1936.

[2]Agronomist, Louisiana Agricultural Experiment Station, Baton Rouge, La., and member of the 1936 Committee on Varietal Standardization and Registration, charged with the registration of cotton varieties.

Under average conditions, plants are from 2 to 2½ feet tall, being somewhat lower and more stocky than most varieties. Branches are rather short-jointed and stout; stems, branches, and leaves hairy; vegetative branches few; leaves medium sized, usually dark green and thick. Flowers are medium sized, cream colored, anthers cream colored; stigma projecting beyond anthers but little, if any; bracts rather large, cordate, and deeply toothed; bolls rather large, 50 to 70 per pound under good conditions, rounded with a short, blunt point, mostly five-locked, stormproof; bolls pick well; length of staple 1 to $1\frac{1}{16}$ inches; seeds medium sized, brownish gray; lint 34 to 36%; resistance to wilt and boll rots only fair; early and more prolific than most large boll cottons.

WASHINGTON, REG. NO. 34

Washington, originally known as Delfos-719, was bred by C. A. Tate of the Stoneville Pedigreed Seed Company, Stoneville, Miss., the original selection being made in 1927 at Stoneville, Miss., from Delfos 6102–324. The original selection has remained constant, later selections having failed to make any improvement. This variety is now grown in parts of Mississippi and Tennessee, seeming to be well adapted in the latter state, and is grown also in south Texas and in the Arkansas River Valley of Arkansas.

On soil of medium fertility, plants attain a height of 2 to 3 feet. They are somewhat lower and more stocky than the plants of most strains of Delfos. Branches are of medium length and medium short jointed; vegetative branches few; stems, branches, and leaves medium hairy; leaves of average size but slightly larger than the average for Delfos; flowers of medium size, corolla cream colored, anthers mostly cream colored; bolls medium large, 60 to 75 per pound, thick, and short taper pointed; fairly stormproof; bracts rather large and deeply serrate; boll pedicels rather short; length of staple $1\frac{1}{16}$ to 1 3/32 inches; lint 33 to 36%; seeds medium sized, brownish gray; susceptible to wilt.

NOTE

A PORTABLE CHAMBER FOR TREATING PLANTS WITH HEAT

SINCE polyploidy is frequently associated with greater size and vigor, qualities often sought by the breeder, the discovery by Randolph[1] that chromosome doubling may be induced artificially by the application of heat at an early stage of embryo development is of great practical interest. During the winter of 1934–35, the writer was interested in finding means by which Randolph's technic, originally applied to corn, might be adapted to other kinds of crop plants. In this he had the valued cooperation of the late Chester Barlow, scientific aid of the U. S. Dept. of Agriculture, to whom the credit for the design and construction of the apparatus to be described is largely due.

Dorsey[2] has shown that chromosome doubling may be induced in wheat and rye by placing the entire plant in a warm room. In order to avoid the risk of heat injury to the vegetative portions of the plant and to gain the advantage of portability we undertook the development of equipment which would enclose only the reproductive parts.

The heating chamber was formed by inserting, telescope fashion, a wide-mouthed quart bottle into a larger glass bottle, 7 inches in diameter and 10½ inches high, from which the bottom had been removed. The two bottles were sealed together with waterproof cement where the neck of the smaller one passed into that of the larger. There remained a space of about 1 inch between the inner and outer glass walls which was filled with water, the capacity of the jacket being about 2 quarts. The glass portion of the apparatus was mounted on sponge rubber pads between two wooden blocks, the mouth of the larger bottle passing through an opening in one of them. This assembly was made rigid with bolts which connected the blocks exterior to the glass walls.

A flexible electrical heating coil of special design was mounted in spiral fashion in the water compartment between the glass walls. The resistance wires within the coil passed through a continuous series of porcelain beads which served to insulate them from the surrounding copper jacket. Electric current was taken directly from a 110 volt circuit. An attempt was made to put the heating device under automatic control, but the thermostat used for this purpose was not sufficiently sensitive to hold the temperature within the desired 1° C range. Manual operation during the comparatively brief periods of treatment, however, proved entirely practicable, although the efficiency of the apparatus could be improved by inserting a rheostat in the circuit to reduce the current as the desired temperature is approached. Thermometers, which were readily visible through the glass walls of the water jacket, are placed in the inner chamber and in the water.

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[1]RANDOLPH, L. F. Some effects of high temperature on polyploidy and other variations in maize. Proc. Nat. Acad. Sci., 18:222–229. 1932.

[2]DORSEY, E. Induced polyploidy in wheat and rye. Jour. Her., 27:155–160. 1936.

The apparatus is suspended over the plant with the open end directed downwards. After the inflorescences to be treated are inserted into the chamber the mouth is closed with cotton batting. The opportunity to follow closely the air temperatures in the vicinity of the plant tissue, the absence of disturbing convection currents, and the relatively large heat capacity of the water surrounding the inner chamber are important factors in the successful operation of the equipment.

Using this device Sanford Atwood, working on *Melilotus alba* in the writer's laboratory, has obtained one tetraploid plant with 2n = 32 chromosomes and one aneuploid individual with 2n = 24 chromosomes from 575 seeds treated in the early embryonic stages. Atwood[3] is presenting the results of this experiment elsewhere.—R. A. BRINK, *Wisconsin Agricultural Experiment Station, Madison, Wis.*

[3]ATWOOD, SANFORD. Tetraploid and aneuploid *Melilotus alba* resulting from heat treatment. Amer. Jour. Bot. (In press) 1936.

BOOK REVIEWS

STATISTICAL METHODS FOR RESEARCH WORKERS

By R. A. Fisher. Edinburgh and London: Oliver and Boyd. Ed. 6. xii + 339 pages, illus. 1936. 15 s.

IN the sixth edition of this well-known work the chapters and section numbers remain the same as in the previous editions. The revision consists mainly of changes and additions of words, phrases, and, in some instances, sentences for the sake of clearness or reference. The following new material has been added: (1) Example 15.1 (under Section 21.1) entitled Complex Test on Homogeneity in Data with Hierarchical Subdivisions, which is given with considerable detail; (2) Working and Hotelling's formula for the sampling error of values estimated by regression (under Section 26); (3) Section 29.2, in which is set forth extended use of successive summation in fitting polynominal regression curves; and (4) a two page extension of Table VI for "1 per cent points of the distribution of *z*."

The text has been increased 18 pages over that of the fifth edition. The other additions consist of new references to literature and bibliography of the author's works, the latter being extended into 1936. The same high quality of press and book work has been retained in the present edition. (F. Z. H.)

RACE, SEX, AND ENVIRONMENT: A STUDY OF MINERAL DEFICIENCY IN HUMAN EVOLUTION

By J. R. de la H. Marett. London: Hutchinson's Scientific and Technical Pub. 342 pages, illus. 1936. 21/.

THIS preliminary study develops many more questions than it answers, as the author remarks in his preface. However, the questions are pertinent and the theories suggested in answer to them are thought-provoking, to say the least. Perhaps the general trend of the book can best be shown by quoting some pertinent statements from the first chapter. "The general hypothesis....a natural selection for an economy of various food substances has played a very important part in guiding the evolutionary process." "More especially the relation of the particular habitat to the ductless glands would seem to reveal a design corresponding to a constant variation of solar radiation, together with the changes in humidity and all the other complex environmental factors...." "The phylogenetic significance of inherited variations in the degree in which secondary sexual characters are expressed is shown to be of primary importance as a means of adapting the species to abundance or deficiency of mineral supply, and to the requirements of arid and humid habitats."

This last sentence illustrates at once some of the virtues and some of the weaknesses of the book. Both sentence and book are too diffuse. Each could and should have been separated into more definite topics. Each topic could have been developed more lucidly by itself and the conclusions dovetailed in a general summary. On the other hand, the statement does stimulate conjectures. Possibly this is all that the author really aimed at in this book.

A list of the chapter headings together with a few of the many subheadings will indicate more clearly the basis for the foregoing criticism. These follow: I. Programme and Biological Background—Race and Sex; Population, Inbreeding, and Sexual Selection. II. A Study of Environment—Classification and Calcium Content of Soils. III. Past Climate and Present Deficiency—Exophthalinic Goitre and Rainfall; New Zealand and Volcanic Soils; IV. Sodium, Potassium and Pigmentation—Drought and the Plant; Sodium, Pigmentation and the Endocrines; V. Mineral Metabolism and the Endocrines—Iron and the Hereditary Blood Groups; Calcium- and Phosphorus-Economy versus Excretion. VI. The Origin of Man. VII. The Human Body—Iodine and the Erect Posture; Specialization and the Mountain Habitat. VIII. Sexual Selection in Human Evolution. IX. Environment and Morphology. X. The Extinct Hommidae—The Food and Form of Neanderthal Man. XI. The Differentiation of Modern Man. XII. Sex and Society—Civilization and Racial Femininity; Ambivalence, Incest and Primal Religion. XIII. Race and Culture—Reaping and Rooting. XIV. Sky God and Earth Goddess—Sex and the Food Instincts; Religion and Environment. XV. Body, Mind and Civilization—Race and Type-Psychology; The Ego Trinity. XVI. Struggles of the Economic Man—The Social Ladder; War and the man. (G. P. Van E.)

DIE METHODEN ZUR BESTIMMUNG DES KALI- UND PHOSPHORSÄURE BEDARFS LANDWIRTSCHAFTLICH GENUTZER BÖDEN

By Dr. Walter-Ulrich Behrens. Berlin: Verlag Chemie. 196 pages, illus. 1935. RM 12.

THIS little book, written in German, brings together under one cover the many methods of determination of these two important soil constituents. After a historical survey of the subject and a discussion of the problems involved, the author first takes up such subjects as the nutrition of plants and mathematical treatment of results of different methods.

The main part of the book deals, first, with the discussion of methods employed in investigations of the potassium and phosphorus requirements of soils and includes results by field methods, physiological and bacteriological methods, plant analysis, and germination methods. Another section deals with the purely chemical methods of research and seems to cover this field quite comprehensively. Still another section of the book deals with plant storage of nutrients and physiological estimation of these nutrients, while the last section includes a few pages on sampling and analytical technic.

The volume includes some 325 literature citations and has an author and subject index. The many workers in this now popular field will find the book interesting and valuable. (R. C. C.)

FELLOWS ELECT

WILLIAM LEONIDAS BURLISON

William Leonidas Burlison, University of Illinois, Urbana, Illinois. Born at Harrison, Arkansas, September 3, 1882. B.S., Oklahoma Agricultural and Mechanical College, 1905; M.S., University of Illinois, 1908; Ph.D., 1915; D.Agr. (honorary) Oklahoma Agricultural and Mechanical College, 1927; Assistant Agronomist, Oklahoma Agricultural and Mechanical College, 1905–1908; Assistant Professor, 1908–1910; Associate Editor, Orange Judd Weeklies, 1910–1912; Associate in Crop Production, University of Illinois, 1912–1915; Associate Professor, 1915–1918; Professor and Chief in Experiment Station, 1918–; Head, Department of Agronomy, 1920–.

Member of American Society of Agronomy. Special interests: Plant physiology as applied to crops and crop production, crop ecology, new uses for major field crops, agronomic and industrial possibilities of new crops.

Dr. Burlison has served the Society as Vice-President in 1925 and 1926, as President in 1927, and, at various times since 1923, as a member of special committees on corn borer investigations, land utilization, corn projects under the Purnell Act, and teaching methods in field crops. He is at present a member of two research committees of the Farm Chemurgic Council. He has made numerous contributions to the literature of crop production.

LEWIS JOHN STADLER

Lewis John Stadler, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture and University of Missouri, Columbia, Missouri. Born at St. Louis, Missouri, July 6, 1896. B.S. University of Florida, 1917; A.M. University of Missouri, 1918; Cornell University, 1919; Ph.D. University of Missouri, 1922; National Research Fellow in Genetics at Cornell and Harvard Universities, 1925–26. Assistant in Field Crops, University of Missouri, 1919–20, Instructor, 1902–21, Assistant Professor, 1921–25, Associate Professor, 1925–, and Senior Geneticist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture since 1931.

Member A.A.A.S., American Society of Agronomy, American Society of Naturalists, The Genetics Society of America, and the Botanical Society of America. His special interests include plant breeding and genetics with particular reference to mutations, their nature and artificial induction by irradiation with X-rays and ultra-violet light. He is recognized as a world authority in these subjects.

Dr. Stadler has been a member of the Society for many years and has served it on numerous committee assignments.

SELMAN ABRAHAM WAKSMAN

SELMAN ABRAHAM WAKSMAN, New Jersey Agricultural Experiment Station and Rutgers University, New Brunswick, New Jersey. Born at Priluka in the Ukraine in Russia, July 29, 1888. Came to the United States in 1910. B.S., Rutgers College, 1915; M.S., 1916; Ph.D., University of California, 1917. Assistant in Soil Microbiology, N. J. Agricultural Experiment Station 1915–16, Microbiologist since 1918. Research Biochemist, Cutter Laboratories 1917–18; Bacteriologist, Takamine Laboratories 1919–20. Professor of Soil Microbiology, Rutgers University since 1930 and Marine Bacteriologist at the Woods Hole Oceanographic Institution since 1931.

Member American Society of Agronomy, International Society of Soil Science, American Chemical Society, Society of American Bacteriologists, A.A.A.S. (Fellow), Society for Experimental Biology and Medicine, Mycological Society of America. Honorary member of Leningrad Microbiological Society, Society of Biological Chemists of India, German Academy of National Sciences at Halle.

Dr. Waksman has been active in the affairs of the Society, serving as a Vice-President for four years, and as a member of the Committee for Reorganization. In 1929 he received one of the Chilean Nitrate of Soda Nitrogen Research Awards for his investigations on the rôle of microorganisms in the transformation of nitrogen in the soil. He was Chairman of the Award Committee in 1930.

He was elected Vice-President of the Third Commission of the International Society of Soil Science in 1924, was Acting President in 1927, and President at the meetings held in 1930 and 1935.

Dr. Waksman is best known among soil scientists for his numerous researches in soil microbiology, including studies of the soil population, the decomposition of organic matter, and the biological and chemical changes involved in the formation of the soil humus. He has also made important contributions to the fields of microbial physiology, enzymes, industrial microbiology, and marine microbiology. His books on "Principles of Soil Microbiology," "Humus," and "The Soil and the Microbe" are well known to all soil scientists with interests in soil microbiology.

AGRONOMIC AFFAIRS

MINUTES OF THE TWENTY-NINTH ANNUAL MEETING OF THE SOCIETY

THE twenty-ninth annual meeting of the Society was held at the Mayflower Hotel in Washington, D. C., on November 17 to 20, 1936. There were 434 registered at the meeting and considerably over 500 in attendance at the various sectional meetings.

The general meeting of all sections of the Society, presided over by President R. M. Salter of the Ohio State University, was held on Thursday, November 19, at 9:30 a. m., and a symposium on "The Scientific Aspects of Soil Conservation" was given as follows:

1. Soil Conservation from the Viewpoint of Soil Physics, Richard Bradfield, Ohio State University.
2. Soil Conservation from the Viewpoint of Soil Chemistry, E. E. De Turk, University of Illinois.
3. Soil Conservation from the Viewpoint of Soil Microbiology, S. A. Waksman, Rutgers University.

On Thursday evening the annual dinner was held, with the address of the President, "An Agronomist Looks at Land Use," as the feature of the occasion (pages 959 to 967 of this number of the JOURNAL). The Crops Section had programs arranged for Wednesday, Thursday afternoon, and all day Friday, and the Soils Section, in cooperation with the American Soil Survey Association, held meetings on Tuesday, Wednesday, Thursday afternoon, and Friday, with programs on soil physics, soil chemistry, soil microbiology, soil fertility, soil genesis, morphology, and cartography, and soil technology. The Committee on Fertilizers of the Society, with its five subcommittees, met on Tuesday with morning and afternoon sessions devoted to the presentation of papers and discussions.

The Auditing Committee appointed by President Salter consisted of Dr. C. J. Willard and Dr. H. J. Harper. The Nominating Committee consisted of President Salter, *Chairman*, F. D. Keim and H. C. Rather of the Crops Section and G. D. Scarseth and Mark Baldwin of the Soils Section.

COMMITTEE REPORTS

VARIETAL STANDARDIZATION AND REGISTRATION

Dr. M. A. McCall, *Chairman*, presented the report of the Committee on Varietal Standardization and Registration which upon motion was adopted as follows:

During the year the Committee on Varietal Standardization and Registration has approved the registration of two wheat varieties, Ramona and Erect, and of three cotton varieties, Deltapine, Ambassador, and Washington. These are described on pages oo to oo of this number of the JOURNAL.

The committee now recommends the registration of sorghum varieties, and following the approval of this recommendation, the registration, as standard varieties, of the 73 sorghum varieties listed in U. S. Dept. of Agriculture Technical

Bulletin 506, as a preliminary step. The varieties listed in this publication are mostly in commercial production. The descriptions given in the publication are adequate and form a satisfactory basis for registration. Regulations covering the registration of improved sorghum varieties are in preparation and will be submitted to the Society for consideration at the next annual meeting. The varieties recommended for registration and their registration numbers are as follows:

1. White durra
2. Dwarf White durra
3. Brown durra
4. Standard feterita
5. Spur feterita
6. Dwarf feterita
7. Hegari
8. Chiltex
9. Premo
10. Ajax
11. Wonder
12. Standard Blackhull kafir
13. Dwarf Blackhull kafir
14. Western Blackhull kafir
15. Texas Blackhull kafir
16. Sunrise kafir
17. Dawn kafir
18. Reed kafir
19. Pearl kafir
20. Rice kafir
21. White kafir
22. Pink kafir
23. Red kafir
24. Manchu Brown kaoliang
25. Standard Yellow milo
26. Dwarf Yellow milo
27. Double Dwarf Yellow milo
28. Standard White milo
29. Dwarf White milo
30. Early White milo
31. Beaver
32. Wheatland
33. Fargo
34. Manko
35. Desert Bishop
36. Bishop
37. Shallu
38. Freed
39. Dwarf Freed
40. Grohoma
41. Darso
42. Schrock
43. Sumac sorgo
44. Early Sumac sorgo
45. Chinese Amber sorgo
46. Minnesota Amber sorgo
47. Waconia Amber sorgo
48. Dakota Amber sorgo
49. Red Amber sorgo
50. Orange sorgo
51. Kansas Orange sorgo
52. Colman sorgo
53. Honey sorgo
54. Sourless sorgo
55. Sapling sorgo
56. Planter sorgo
57. Gooseneck sorgo
58. Leoti sorgo
59. Folger sorgo
60. White African sorgo
61. Atlas sorgo
62. McLean sorgo
63. Rex sorgo
64. Collier sorgo
65. Denton sorgo
66. Sugar Drip sorgo
67. Evergreen broomcorn
68. Black Spanish broomcorn
69. California Golden broomcorn
70. Evergreen Dwarf broomcorn
71. Scarborough broomcorn
72. Japanese Dwarf broomcorn
73. Black Spanish Dwarf broomcorn

Action by the Society is recommended as follows: (1) Approve registration of sorghum varieties, and (2) approve the registration of the 73 sorghum varieties listed above as standard varieties, delaying registration of improved varieties pending the submission and approval by the Society of registration regulations.

H. B. BROWN
J. A. CLARK
E. F. GAINES
H. K. HAYES
W. J. MORSE
J. H. PARKER
T. R. STANTON
G. H. STRINGFIELD
M. A. MCCALL, *Chairman*

BIBLIOGRAPHY OF FIELD EXPERIMENTS

The report of the Committee on the Bibliography of Field Experiments as presented by H. M. Steece, *Chairman*, was received and ordered printed in the proceedings as follows:

The committee has compiled a bibliography of 71 titles of the more important contributions on the methodology of and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography published in the JOURNAL (Vol. 25:811–828, 1933; and the additions in Vol. 27: 1013–1018, 1935.)

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F. R. IMMER — H. M. TYSDAL
J. T. MCCLURE — H. M. STEECE, *Chairman*

PASTURE RESEARCH

Dr. P. V. Cardon, *Chairman*, presented the report of the Joint Committee on Pasture Research, which upon motion was adopted as follows:

The primary objective of your Committee during the last few years has been to work with similar committees of the American Society of Animal Production and the American Dairy Science Association in the completion of a joint report on Pasture Investigation Technic. That report, in preliminary form, was mimeographed in March, 1936, and sent to all state experiment stations and other interested agencies. It evidently has been regarded as generally satisfactory since only a few suggestions for relatively minor changes have been received. It is proposed, therefore, that the preliminary report be accepted by the American So-

ciety of Agronomy subject to such periodic revision as in the judgment of the joint committees may later seem advisable in the light of further developments.

The technic of the pasture problem does not differ in principle on range pastures from that on cultivated pastures, as indicated in the tentative recommendation of technic for grazing experiments on range pastures in arid and semi-arid regions, submitted as a supplemental report of your committee last year. (See this JOURNAL, Vol. 28, No. 1, January, 1936.)

Any report on technic in range and pasture investigations must for obvious reasons be regarded as incomplete, since new investigations are constantly being undertaken the results of which probably will justify modification of earlier recommendations. Since the last report of your committee, for example, the JOURNAL has carried an excellent article by Stewart and Hutchings on a new method of range vegetation survey. (See this JOURNAL, Vol. 28, No. 9, September, 1936.) This method will doubtless be considered in connection with future reports of your committee on matters of this kind. Again, at Madison, Wisconsin, a federal-state cooperative study comparing recommended pasture measurement methods is under way and the results of that study will be of importance to all persons interested in pasture investigations. Similar interest will be displayed in the results of pasture technique studies in progress at Wardensville, West Virginia; Kylertown, Pennsylvania; Beltsville, Maryland, and other places. It is the purpose of your committee to keep in touch with developments in this field of research and make revised reports as circumstances warrant. In the meantime, agronomists and other workers in pasture research will find much of value to them in the report which has been distributed.

Your committee desires to call to your attention the fact that under the impetus of renewed and widespread interest in improvement, unusual activity is apparent among research agencies and more experimental work with pastures is now in progress than at any previous time. It is more important than ever before, therefore, that this Society through its Joint Committee on Pasture Research continue cooperation with the American Society of Animal Production and the American Dairy Science Association with a view to promoting the closest possible correlation of research in pasture and range improvement.

Much research with pasture plants themselves is now in progress, which has a direct bearing upon range and pasture improvement. Mention may be made, for example, of (a) comparative tests of native and introduced range and pasture plants; (b) selection and breeding for improvement of important species; (c) methods of increasing and maintaining seed supplies of superior strains; (d) genetic studies of pasture plants, and (e) morphological, physiological and pathological research with pasture plants. It is the intention of your committee to keep informed on the results of the newer research with pasture plants and help by whatever means are at its disposal to have them fully considered in connection with future reports on range and pasture studies.

Your committee proposes, also, to encourage where practicable additional research on pasture and range problems upon which there is a lack of adequate information, as for example, (a) the control of weeds in pastures, (b) the value of shade in pastures and the methods of supplying it, (c) inventory of forage conditions on irrigated pastures, (d) influence of drainage on pasture species, (e) effect of rotation grazing on irrigated pastures with special reference to effects of rest periods after irrigation, and (f) variations in pasture mixtures for different degrees in wetness in pasture lands. There is need, also, for further research with

methods of pasture measurement and means of promoting accuracy in range and pasture investigations generally.

In view of the present widespread interest in range and pasture improvement, watershed protection, and erosion control, the possibility and advisability of effecting close correlation of all activities in this field is an ideal which this Society can well afford to foster. With your permission, the Joint Committee on Pasture Research will continue to do everything possible to bring about a realization of that ideal.

O. S. AAMODT	D. R. DODD	PAUL TABOR
A. E. ALDOUS	H. D. HUGHES	H. N. VINALL
B. A. BROWN	GEORGE STEWART	P. V. CARDON, *Chairman*

FERTILIZERS

Dr. R. M. Salter, *Chairman*, presented the reports of the five subcommittees of the Committee on Fertilizers, which upon motion were adopted as follows:

Reports of the five sub-committees making up the Committee on Fertilizers were presented by R. M. Salter, general chairman, as follow:

Sub-Committee on Fertilizer Application.—This committee has continued to function as one of the constituent sub-committees of the National Joint Committee on Fertilizer Application. During the past year the activities with respect to placement of fertilizer have been more comprehensive than heretofore.

Fertilizer placement experiments were conducted during the past season at 68 locations in 16 states with lima, snap, string, and white beans, cabbage, carrots, celery, corn, cotton, kale, onions, peas, potatoes, spinach, sugar beets, tobacco, and tomatoes.

The study of other phases of fertilizer application has also been undertaken. The effect of different sizes of fertilizer particles and of granulated homogenous mixed fertilizers has been given attention.

There has been completed a nation-wide survey of the most common fertilizer application practices on farms. The survey was divided into three parts covering different classes of crops, (1) vegetable crops, (2) field crops, and (3) fruits and nuts. The survey reports on vegetable crops and field crops have been completed and distributed. The survey covering fruits and nuts was started at a later date, and the final report will soon be available.

A survey of available fertilizer distributing equipment was also completed during the year on which a report has been issued. The specifications of each machine sought in this survey were the following: Placement of the fertilizer in the soil, crops and/or conditions for which intended, the approximate range of quantities of fertilizer dispensed, the type of dispensing mechanism, size, and general type.

ROBT. M. SALTER, *Chairman*

Sub-Committee on Soil Testing.—The sub-committee's activities during the year have been confined to the organization of a program of four papers on subjects pertaining to soil testing, presented at the American Society of Agronomy meeting (Soil Fertility Section) A. M. Nov. 18, and to discussion of future work if continued. A meeting of the sub-committee was held at 4 P. M., Nov. 18, and the following recommendations were suggested:

1. That the Bureau of Chemistry and Soils be asked to cooperate in correlative study of "quick tests" to the extent of assembling a series of soils of known ferti-

lizer response, representing important types in all of the major soil groups for the purpose of making samples of same available for check determinations by various methods.

2. That a monograph be prepared for the purpose of outlining the characteristics and limitations of all the rapid chemical soil tests that have been proposed by American research workers or that are in commercial use. The sub-committee should cooperate in this work, but in its final form it should represent the judgment of a disinterested authority.

3. That the sub-committee continue to function as a clearing house in the exchange of ideas pertaining to the technique and interpretation of "quick tests".

4. That the extent of soil testing by commercial agencies within the various states be surveyed, with a view to the encouragement of a better understanding of the value and limitations of quick tests as a guide to recommendation of fertilizer practices.

M. F. MORGAN, *Chairman*

Sub-Committee on Acidity and Basicity of Fertilizers.—In the 3 years since its appointment the committee has satisfactorily completed the following details of the work outlined:

The modified Pierre method has been adopted by the A. O. A. C.

The value of non-acid-forming fertilizers under critical soil conditions has been demonstrated.

It has been shown that magnesium deficiency can be controlled to a considerable extent by the use of dolomitic limestone as a neutralizing agent.

The relative effect on the soil pH of dolomitic limestone of different particle size has been shown.

The reactions of basing having increased the efficiency of dolomitic limestones in fertilizers. A comprehensive study of chemistry of these reactions is in progress and preliminary reports have been made.

A method for determining the relative solubility of different grades of dolomitic limestone has been developed.

The chief remaining problem deals with the efficiency of the neutral fertilizers in relation to soils and crops. Several years of field experimentation will be required before satisfactory conclusions can be reached.

At a meeting of the sub-committee held on Nov. 17 it was decided to recommend that the sub-committee be continued so that it can resume its active functions whenever any new aspects of the problem are presented or the accumulation of experimental evidence justifies further attention.

L. G. WILLIS, *Chairman*

Sub-Committee on Symptoms of Malnutrition in Plants.—The work of the Committee during the past year has consisted of varied activities. Two meetings were held, one at Jackson, Miss., and the other in Washington, D. C. A survey of available material was conducted by Mr. Hazen and a summary of this information is planned. The exhibit of material consisting of living plants and around two hundred illustrations, many in color, is now on display at the meetings of the Society.

In view of the magnitude of the undertaking it is recommended by the Committee that the work be concentrated on studies of malnutrition due to deficiencies of the commoner elements, namely, nitrogen, phosphorus, potassium,

calcium, magnesium, sulphur, manganese, iron and boron on the principal crops, for example, corn, cotton, tobacco, fruit and vegetables.

J. E. McMurtrey, Jr., *Chairman*

Sub-Committee on Fertilizer Ratios.—The committee feels the need of bringing some degree of order from the chaos that engulfs the fertilizer grade situation is so evident all interested will agree that some effort in this direction should be made. There are two main objectives. First, to reduce the number of grades offered for sale and used in any given territory. Second, to increase the plant food content of fertilizers as rapidly as is consistent with good practice, both in use and manufacture.

Various plans for accomplishing these ends have been considered. The most feasible proposal appears to be the adoption of a unified scheme or system for the selection of fertilizer grades. Of the systems discussed the 12 point triangle is the most promising. This triangle appears to offer a sufficiently wide range in ratios to meet the requirements of soils and crops in old sections of the country. Undoubtedly many ratios appearing on the 12 point triangle will not be needed. The committee is proceeding with a careful study to determine if ratios found by experimental work to be needed in different states may be satisfactorily supplied from those on the triangle.

The committee wishes to emphasize the following points:—

1. There is no "best" fertilizer for any given crop on any soil type. There are usually several fertilizer grades which during a period of years will prove equally desirable.
2. That for experimental purposes adherence to any list of accepted grades or scheme for the selection of grades is unnecessary and unwise. The experimentalist should cover the entire range of possibility; and when he has determined the proper ratio of nutrients for a given crop under given soil conditions, he will find in the accepted list a fertilizer grade which meets the requirements for all practical purposes.
3. Progress toward simplification of the fertilizer grade problem will be slow, unless agronomists come to some agreement and then stick stubbornly by their decision.
4. The cooperation of the fertilizer industry is essential.

C. E. Millar, *Chairman*

STUDENT SECTIONS

The report of the Committee on Student Sections was presented by Prof. H. C. Rather in the absence of the Chairman and other members of the committee. Upon motion the report was adopted and the prizes were awarded, checks for $15 and $10 being awarded to the first and second winners, respectively, and a subscription to the Journal going to the first, second, and third winners. The report of the Committee and abstracts of the first, second, and third prize essays follow.

During the past year the Student Section of the American Society of Agronomy has approved the petitions of agronomy students of the following institutions: Clemson College, South Carolina, Louisiana State College, Mississippi State College, and Michigan State College. A total of 13 institutions are now members

of the Section. Several schools have indicated an interest in the organization but have failed to petition for affiliation.

Under the leadership of Jeff L. Horn, Texas A. & M. College, the students have perfected a union of their various chapters. They plan to hold meetings this fall in Kansas City and Chicago.

Thirteen papers were entered in the essay contest sponsored by the American Society of Agronomy. The essays were judged by Professors A. L. Frolik, University of Nebraska, J. W. Zahnley, Kansas State College, G. H. Dungan, University of Illinois, and C. O. Rost, University of Minnesota. In addition, advice was secured from colleagues of the committee members regarding reliability of content and general value of the paper. The first six papers and their authors are:

1. The Rôle of Potassium in Plant Nutrition, I. C. Gregory, North Carolina State College.
2. The Importance of Soil Conservation, Leonard C. Hoegemeyer, University of Nebraska.
3. Breeding for Black Stem Rust Resistance in Spring Wheat, Torleif Boe, University of Minnesota.
4. Pasture Improvement in the United States, Geo. W. Huey, Iowa State College.
5. Pasture Improvement in the United States, Walter Abmeyer, Kansas State College.
6. Pasture Improvement in the United States, Chas. F. Greenbacker, Connecticut State College.

The Committee recommends that abstracts of the first three papers be published in the JOURNAL as a part of this report and that the Society sponsor the contest for another year.

The committee recommends that the Society print certificates or diplomas to be awarded to each institution affiliating with the national organization, these certificates to serve as charters for the various groups.

THE ROLE OF POTASSIUM IN PLANT NUTRITION

I. C. GREGORY, *North Carolina State College*

Evidence is given of three functions of potassium in plants, one of them essential in the physiological processes, one a protective function controlling the intake of iron and aluminium and the third which is relative to other cations is defined as antagonism.

Generally speaking potassium appears to control the tone and vigor of plants by balancing the effects of nitrogen and phosphorus. Since no indispensable organic potassium compounds are found, the effect of potassium is thought to be relative to various plant process which are carbon dioxide assimilation, reduction of nitrates, cell division, and synthesis of proteins of the meristematic tissue. The conducive influence of potassium on carbohydrate synthesis is apparently contradicted by the presence of large amounts of available carbohydrates in plant tissue even in the case of potassium deficiency. This inconsistency is eliminated when account is taken of the possibility that the carbohydrate accumulation is due to the retardation of protein synthesis due, in turn, to a lack of potassium. It has been found, further, that potassium taken up by young plants may be retranslocated later and reutilized. From this mobility of potassium and its movement in potassium deficient plants to meristematic tissue it has been concluded that potassium is essential for cell division.

Evidence as to the corrective effect of potassium for iron and aluminium accumulations is also probably related to translocation. It was found that iron and aluminium accumulations in the nodes of corn were effectively reduced by potash. That this is most likely distinct from the strictly nutrient function of potassium is the conclusion drawn from experiments showing that copper sulphate bears the same relation to such accumulations as does potassium. There is a possibility that this effect is associated with the fixation of potassium in the form of a secondary silicate mineral in which iron or aluminium may be a component.

An additional need for potassium is concerned with the antagonism of potassium to other cations, particularly to calcium. It is not improbable that a part of the benefits derived from fertilizers containing potassium are due to an antagonistic effect toward calcium rather than to a nutrient effect alone.

The Importance of Soil Conservation

Leonard C. Hoegemeyer, *University of Nebraska*

The conservation of the soil, the nation's most valuable and most extensive natural resource, is necessary. Conservation is a national problem because the control of the widespread soil erosion and soil depletion will affect the nation's future progress and prosperity. It is essential, therefore, that the destructive processes of erosion and soil depletion should be slowed down.

Water and wind are the most common forces which destroy the soil. Where the volume and the velocity are great, gullying is likely to occur. This may result in totally destroying a field which was cultivated or grazed and may even lead to the consequent abandonment of a farm. Sheet erosion is much less noticeable than gullying; however, it is much more prevalent and costly. The fertile top soil, valuable plant nutrients, and organic matter are removed. Extreme erosion and runoff in a watershed may result in flood conditions which in turn may destroy bottom lands by deposition of sand, silt, and debris, and by washing or in the sedimentation of reservoirs. Huge investments naturally are lost.

The largest portion of wind erosion is found in the Great Plains states. Winds blow immense quantities of loose dry soil high into the air. The atmosphere, at times, becomes so dense with the dust particles that the sun is nearly obscured. Dust clouds have been observed over 1400 miles from the point of origin and even over 300 miles out over the Atlantic ocean. Such destruction by blowing, not only causes great losses of top soil, plant nutrients, and organic matter, but also accelerates human misery.

The maintenance of soil fertility depends upon the control of erosion, the amount removed by crops, and the amount of leaching and volatilization. The control of these depleting forces is also essential for the conservation of the soil. In drier regions, the organic matter is necessary not only to maintain soil fertility, but also to bind the soil, consequently decreasing its susceptibility to wind erosion.

The economic factors, land tenure, low prices, and debt burden are closely interrelated with the increasing amount of soil erosion and soil depletion. The increase in tenancy, in short leases, in high mortgages, and in the already numerous tax-delinquencies have been contributing causes of the so-called "soil mining and exploitation." Adjustments of these factors seems very necessary and very important if soil conservation is to be a success.

The realization, during the past several years, that the land is the source of all life has led to a new attitude toward this fundamental problem. It is commonly

recognized that our heritage of fertile productive land must be maintained and passed to posterity, and at the same time, it must provide a high standard of living. Soil conservation then is essential and necessary to protect that basic heritage and the source of all cultural advancement, progress, and prosperity.

Breeding for Black Stem Rust Resistance in Spring Wheat

Torleif Boe, *University of Minnesota*

The wheat plant is not a native of America, but was brought over by the early pioneers from the different parts of the world. The only way that the early wheat growers could improve their stock was by introduction from foreign countries. Later progressive farmers and seedsmen began to improve their stock by selection of desirable plants, and about 1870 a third method of improving wheat came into use, namely hybridization, or by selection of artificial crosses.

The first breeders were farmers and seedsmen, but about 1890 the work was taken up by trained men from the U. S. D. A. and the several state experiment stations.

At first very little was known of the mode of inheritance but the rediscovery of Mendel's law gave a great impetus to the science of genetics and plant breeding.

The black stem rust is one of the most destructive grain diseases in the world and causes enormous losses to grain growers in the United States.

The black stem rust can be controlled in two ways (1) by destroying the alternate host of the disease, the common barberry bush, or (2) by growing rust resistant varieties.

It has been shown that there are numerous strains of the stem rust of wheat which can be differentiated only by their action on various varieties. Three types of resistance are known, physiological, morphological, and functional.

In breeding of wheat for rust resistance, various methods have been devised and these the breeder should become familiar with. However, to understand and apply them he must be conversant not only with agronomy, but also be familiar with plant pathology. That is, in addition to knowing the varietal characteristics of the various grains, their physiology and adaptation to soil and climate, he must also know the different rust species, their methods of wintering, the optimum periods of infection and development, the climate and soil conditions favorable and unfavorable to the epidemics—in fact all the important points in the taxonomy, life history and physiology of these diseases.

The first step in producing a rust resistant variety of spring wheat is to select the parent plants. The plant breeder must choose carefully to obtain strains that possess the agronomic and rust resistant characters that he wants recombined in the new variety. The method commonly employed by most experiment stations consists of growing the progenies from crosses in single plant rows to enable a study of individual plants. In the F_2 and later segregating generations in heterozygous lines, an artificial rust epidemic is produced by hypodermically inoculating susceptible varieties in the border rows. From these centers of infection the disease will spread, under favorable conditions in the breeding nursery. Rust resistant plants with desirable agronomic characters are selected and again planted to study their reaction to rust. At the end of the F_5 or F_6 generation plants within lines homozygous for rust resistance are bulked and planted in rod rows for a study of yield and other desirable agronomic characters. If the variety is good enough it is sent out to growers for testing and milling and baking quality are

found out. Then, if the variety is good enough, it is sent out to the wheat growers in the state.

Many outstanding achievements have been made in breeding for disease resistance in crop plants.

Thatcher, a spring wheat variety produced by Hayes, Stakman, Ausemus and their associates at the Minnesota Station; Hope and H-44 wheats produced by E. S. McFadden of the U. S. Department of Agriculture; Ceres produced by L. R. Waldron of the North Dakota station; Marquis produced by Charles E. Saunders of Canada, are landmarks in the production of spring wheats. Many others, both in wheat and other crops, stand out as invaluable contributions to crop improvement.

A. L. Frolik J. W. Zahnley
G. H. Dungan H. K. Wilson, *Chairman*
H. W. Staten

RESOLUTIONS

Dr. F. D. Keim, *Chairman*, presented the report of the Committee on Resolutions which upon motion was adopted as follows:

Following the procedure established with the appointment of a standing Committee on Resolutions, your committee has continued as one of its functions, to take note of the death of agronomists who have long been active in their lines of work. It is with sorrow and a feeling of great loss, not only to the Society, but to their respective families, that we must record the deaths ot J. N. Harper of Georgia, a charter member of the Society; C. E. Thorne of Ohio; N. A. Pettinger of Virginia; S. D. Connor of Indiana; and F. S. Wilkins of Iowa. A statement regarding the life and work of each of these men is made a part of this report.

The Resolutions Committee also recommends the following:

Inasmuch as the recent economic conditions have profoundly affected the farmer, both from the standpoint of economic return and his social well-being, and inasmuch as these conditions have made it strikingly evident that fundamental land use adjustments are imperatively needed, and inasmuch as proper readjustments can only be based on a properly prepared soils inventory,

Be it resolved that this Society memorialize the Secretary of Agriculture regarding the importance of securing funds for the completion of this inventory within the next decade.

R. J. Garber J. D. Luckett, *ex officio*
M. F. Miller F. D. Keim, *Chairman*
R. I. Throckmorton

Joseph N. Harper

Dr. Joseph N. Harper, for many years identified and widely known in connection with soil fertility interests in the South, passed away at his home in Atlanta, Georgia, July 1. His many friends who had known of his poor health due to a heart ailment, nevertheless were sadly shocked, since he had been active up to within a few days of his death.

Few agriculturists in the South have been more closely allied with its soil fertility problems than Joe Harper. Born March 11, 1874, and reared on a farm in Winston County, Mississippi, he began his advisory career with his appoint-

ment in 1898 as Agronomist to the Kentucky Experiment Station where he made notable contributions on the culture of tobacco, corn, wheat, and hemp.

In 1904 he installed at the St. Louis fair a Kentucky agricultural exhibit which won a grand prize and many medals and led to a special invitation from the Department of Agricultural Technology of Ireland to visit that country and conduct experiments with tobacco. While abroad, Dr. Harper studied soils and methods practiced by farmers in maintaining soil fertility in the British Isles.

In 1905 he was called to head the Department of Agriculture of Clemson College, South Carolina, and direct the activities of the South Carolina Experiment Station. These positions he held for 11 years, and under his direction the Research Department of Clemson College grew to become recognized as a leading experiment station dealing with problems of soil fertility and plant diseases.

Dr. Harper, in 1917, was chosen to direct the extensive work of the Soil Improvement Committee of the Southern Fertilizer Association. His sound scientific knowledge and practical judgment won for him, in his travels all over the South, the respect of all concerned with the maintenance and building up of soil fertility.

After a year as Director of the Department of Crop Fertilization of W. R. Grace & Co., in 1925 Dr. Harper accepted a position as director of agricultural research for the Societe Commerciale des Potasses D'Alsace with headquarters in Atlanta. With the formation of N. V. Potash Export My., Inc., Dr. Harper became a Director of this company's Agricultural and Scientific Bureau, in charge of the Southern Territory, which position he held until the formation of the American Potash Institute, Inc., in July 1935. For the Institute he was manager of the Southern territory.

Dr. Harper held memberships in many scientific societies and had held every office in the Association of Agricultural Workers, which is composed of the leading agricultural scientists of the South. It has been said of him that his success was due not only to his scientific knowledge, but to his practical knowledge of farming, and that when he talked to farmers he had his own experience ot a lifetime of farming from which to draw upon.

He is survived by Mrs. Harper, whom as Miss Susan Sparks he married in 1898, and by one daughter, Lucy Elizabeth.—R. H. STINCHFIELD.

CHARLES EMBREE THORNE

Dr. Charles E. Thorne, director emeritus of the Ohio Experiment Station and often referred to as the "grand old man" of agriculture, died at his home in Wooster, February 29, at the age of 89 years.

Dr. Thorne was born on a Greene County, Ohio, farm October 4, 1846, of sturdy pioneer stock and educated in the country school of that district. After teaching a few terms he entered Michigan Agricultural College in 1866 and completed his education at Antioch College, at Yellow Springs. After a few years of farming he was made manager of the college farm at the Ohio Agricultural and Mechanical University, now Ohio State University, at Columbus.

It was his ambition to develop a practical laboratory for agricultural research at the university farm, but as his idea received little encouragement he resigned after four years to take a position on the editorial staff of *Farm and Fireside.*

In 1887 he became Director of the Ohio Experiment Station at Columbus, helped choose a new location and move the Station to Wooster the next year. Under his leadership the Ohio Station developed into one of the outstanding in-

stitutions of the country. He served as Director for 34 years when his resignation, tendered two years previously, was accepted in 1921 and he was honored by being made Director Emeritus.

In 1916 Dr. Thorne was chosen president of the Society for the Promotion of Agricultural Science and of the Association of American Agricultural Colleges and Experiment Stations.

Throughout his life Director Thorne was a constant seeker after the truth, a philosopher, a Christian gentleman in the truest sense, and a keen observer and writer. He always maintained that common touch that kept his work at the station of an intensely practical nature. Many an Ohio farmer has received personal help and inspiration from this kindly gentleman, and no one can estimate the grand total, both monetary and otherwise, of the influence of his studies upon farm practices in Ohio today.

Such patience as he exhibited, both in seeking the answers to agricultural problems and in time of trouble, is a rarity in the world today and Ohio is going to miss him sorely.

The nation will likewise miss this man who was so prominent at all gatherings of agricultural scientists. The foundation of the long-time soil fertility work that he early laid at the Ohio Station not only served its purpose in building Ohio agriculture upon a sound basis but has since become the model and forerunner of this type of work throughout the nation.

Dr. Thorne's passing will be missed both at home and throughout the scientific world.

N. A. Pettinger

Dr. N. A. Pettinger, Associate Agronomist in the Virginia Agricultural Experiment Station and Assistant Professor in the Virginia Polytechnic Institute, died at the Roanoke Hospital in Roanoke, Virginia, on February 1, 1936. He had been confined to his bed for the previous eight months due to a heart ailment.

Dr. Pettinger was born on December 15, 1901, near Shannon City, Iowa, where he received his grammar and high school education. In the fall of 1919, he registered at the Iowa State College in the course in Farm Management but after two years transferred to Farm Crops and Soils, in which field he received his B. S. degree in June 1923. Having decided to pursue the scientific field as his chosen life work, he matriculated in the graduate school at the University of Illinois, where he had received a scholarship in Agronomy, in the fall of 1923. His major field of study was Plant Breeding with Plant Physiology as a minor. After receiving his M. S. degree in June 1924, he was appointed to a full time assistantship in the Division of Crop Production of the Illinois Agricultural Experiment Station, which position he held until September 1, 1925. From September 1, 1925 to September 1, 1926, he was half-time assistant in the Division of Crop Breeding at the Illinois Station. He was then appointed a fellow in Agronomy and graduated with the Ph. D. degree on June 15, 1927. On September 1, 1927, he was appointed to the post in Virginia which he held until his death.

Although Dr. Pettinger was only thirty-four at the time of his death, he had made a decided contribution not only to the Station and College where he spent most of his labors, but also to the field of Agronomy in general. He was considered one of the outstanding young research men in this country in the field of Agronomy. His principle research interests were in the field of plant indicators of plant food requirements and he had published several papers on phases of this general topic. He was a leader in the field of soil testing and was Chairman of the Sub-

committee on Soil Testing of the American Society of Agronomy. He had conducted considerable research in regard to the rôle of minor elements in plant growth and was also a member of the Committee of the American Society of Agronomy on Malnutrition of Plants. A bulletin and chart showing the effect of pH on availability of plant nutrients published just before his death brought him national recognition.

Besides his ability in research, he was frequently cited by students and others of the teaching staff as the outstanding instructor in the School of Agriculture.

Dr. Pettinger was an active member of the American Society of Agronomy and held membership in the following honorary societies: Gamma Sigma Delta, Phi Sigma, Alpha Zeta, and Sigma Xi.

He was married on December 24, 1927 to Miss Bernice Phillippe and at his death was survived by his wife, one daughter, and one son.—S. S. OBENSHAIN.

SAMUEL DICKEN CONNER

In the passing of Samuel D. Conner, Research Chemist in the Purdue University Agricultural Experiment Station, who died on April 19 following an emergency operation for appendicitis, the Society has lost a well-known and valuable member.

Professor Conner was born in Connersville, Indiana, June 17, 1872. After graduation from the local high school he entered the School of Science in Purdue University and received the Bachelor of Science degree in 1894, majoring in chemistry. After several years' service as chemist with a sugar refinery in the South and as a salesman in the fertilizer industry he returned to Purdue University in 1899 as a member of the State Chemist's staff. In 1905 he became Assistant Chemist and three years later Associate Chemist in the Department of Chemistry of the Agricultural Experiment Station. From 1906 to 1913 he also served as Instructor and Assistant Professor of Agricultural Chemistry in the School of Agriculture. In 1907 he received the degree of Master of Science. In 1912 he was appointed Associate in charge of chemical work in the Department of Agronomy and in 1923 was also placed in charge of the newly organized Research Chemical Laboratory with the title of Research Chemist.

Professor Conner was a true scientist with an open mind on all questions, and was always digging into some new problem. His researches dealt largely with the chemistry of soils. He was a pioneer in the study of soil acidity and became a widely recognized authority on the subject. His studies of muck and peaty sand soils pointed the way to making millions of acres of these defective soils profitably productive. His discovery in 1912 of aluminum toxicity under certain soil conditions and of borax injury to corn from certain fertilizers that came into use during the World War were other noteworthy results of his work. In recent years he made valuable contributions to knowledge concerning fixation by the soil of applied phosphate and potash fertilizers and the placement of plant food for greatest efficiency.

Professor Conner made about one hundred contributions to the literature of soil science through journal articles and the publications of the Purdue University Agricultural Experiment Station. He held membership in a number of national and international societies devoted to chemistry and soil science, often taking part in programs and serving on important committees. At the time of his death he was a member of three committees of this Society.

In the passing of Professor Conner soil science has lost a keen student and

the farmers of Indiana, in particular, have lost a valuable counselor who cannot be replaced short of many years. His broad and intimate knowledge of the soils of the State, derived from years of intimate contacts and studies in both field and laboratory, enabled him to prescribe profitable soil treatments under almost any situation and many thousands of farmers have benefitted through his advice. His genial personality and helpful cooperation will long be missed by his colleagues in Purdue University and the host of friends throughout the state, as well as by the many soil scientists in other institutions with whom he had many years of friendly personal acquaintance and professional interchange of ideas.—A. T. WIANCKO.

FRANKLIN SCOTT WILKINS

On April 3, 1936, after 20 years of service to this institution by Franklin Scott Wilkins, more familiarly known among us as "F. S." or as "Scott" Wilkins, his earthly remains were interred in the College Cemetery, reserved for the burial of those who have served Iowa State College and the people of the state faithfully and long. He is survived by his wife, Eleanor Selover Wilkins, whom he married in 1920, and by two children, Donald, age 14, and Joan, age 9.

F. S. Wilkins was born at Addison, Pa., Nov. 18, 1889. While he was still a mere boy the family removed to a farm in South Dakota, from which environment he enrolled at the South Dakota State College of Agriculture. During his four years as a student at that institution he developed marked leadership qualities which were soon recognized and he was accorded positions of responsibility and honor by students and faculty alike. In his last year he served in the most responsible student position on the campus, that of president of the student governing body. He was granted the Bachelor of Science degree in 1914. The same year he was awarded a fellowship in Farm Crops at Iowa State College and was granted the Master of Science degree in 1915. Upon the completion of the year of graduate study he was employed as an instructor in Farm Crops at the Iowa State College, continuing in this position until 1918 when he resigned to offer himself for military training. During the years 1919–1920 he was on the staff of the Oregon State College as Assistant Professor of Farm Crops, returning to Iowa State College in 1920 as Research Assistant Professor in Forage Crops, continuing in this position to the time of his death. From 1928 he also was in the employ of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, directing the extensive investigations which that Division had elected to locate at Ames in cooperation with the Iowa Station.

Nature had endowed him with an intense interest in all growing, living things and a mind which demanded to know how and why they responded as they did to their environment, thus making him an ideal crops experimentalist. In his investigational work no procedure was too detailed or laborious to be followed through, once he was convinced that it offered the best means of getting accurate results. It is believed that few experimentalists have been more careful and accurate in making and preserving in the most systematic order their recorded observations. Above all he is known always to have been absolutely honest.

Mr. Wilkins was a member of the honorary professional groups, Alpha Zeta and Phi Kappa Phi; also a member of the American Society of Agronomy, the Society of Plant Physiologists, the Iowa Academy of Science, and the National Soybean Association.

Mr. Wilkins did not have the blessing of good health. For a period of years it was necessary for him to subsist on a most rigid diet, a diet which often brought

physical weakness. During recent months there had been almost continual distressing pain, such distress resulting in sleepless nights or fitful rest. But through it all he carried on his work almost continuously, never complaining or referring in any way to his own condition. On the contrary, one of his most conspicuous characteristics was his sympathetic concern and active interest in the difficulties and troubles of others. In spite of his physical handicap, by thoughtful, careful effort and planning he carried on his work effectively, accomplishing more than many another, possessed of good health, might have done.

One of the most notable of Professor Wilkins' contributions to our knowledge of forages was the results obtained from an investigation of the factors involved in the successful production of soybeans, these results being made available in Iowa State Bulletins 228 and 309. These publications report the results of very thorough and comprehensive studies having to do with all phases of soybean production. With the printing of the first of these bulletins many letters came to the station stating that this publication represented by far the most thorough, comprehensive, and well-reported study of soybean production thus far available. During the period represented by these studies and since, the acreage of soybeans in the state increased from a few hundred to over a million, or more than one-tenth the 1935 Iowa corn acreage.

Investigations which Mr. Wilkins carried through a period of years with Sudan grass, when this plant first became available, probably were also more thorough and comprehensive than any similar effort anywhere in the corn belt.

It is particularly fortunate that the results of a great variety of studies which have been underway through a considerable period of years having to do with the different legumes and grasses, either have recently been reported and published by the Iowa Experiment Station, or are now ready for publication. The first of these "Choosing Legumes and Perennial Grasses" Bulletin 331, was issued by the Iowa Station in June 1935. A companion publication "Establishing Stands of Legumes and Perennial Grasses" is now in manuscript form ready to be submitted for publication. The manuscript for another publication, having to do with investigational methods employed in conducting forage crops research and to which Mr. Wilkins gave his best efforts for several years, was completed only a few days before his death.

Other investigations to which Mr. Wilkins gave a great deal of his energy through a period of years had to do with alfalfa, red clover, and sweet clover, those three most important of our small-seeded legumes. The results of much of this work remain to be published, but fortunately, as a result of the meticulous care exercised in the recording and filing of experimental records, it will be possible for others to complete the reporting of these results with some degree of satisfaction.

But the reports of the forage crop investigational work have not been limited to the publications of the Experiment Station. Professor Wilkins was a writer of recognized ability with an urge to write. He has written extensively for *Wallaces' Farmer and Iowa Homestead*, the agricultural journal which blankets Iowa farms, the greater part of this material having been published without any indication of its source. It was written with a desire that the results of investigations to which he was devoting his energy be made available as quickly as possible for practical application in the solution of Iowa farm problems.

With the passing of Franklin Scott Wilkins, it is recognized that the staff of the Iowa Agricultural Experiment Station loses the services of a co-worker of recognized ability and standing in his field of research, a man of the very highest

character, interested in the most worth while things in life, an asset to the civic and religious life of the college community, and a valued friend and counsellor.—P. E. BROWN.

ORGANIZATION OF AND PROGRAM FOR EXTENSION WORKERS

Prof. J. S. Owens presented the report of the special committee appointed to consider the possibility of organizing the extension workers and of arranging an extension program in connection with the annual meetings of the Society. Upon motion the report was adopted as follows:

In September, 1936, President R. M. Salter appointed the men named below "to serve as a committee to canvass the opinion of extension men, both prior to and at the November meetings, and to bring to the Executive Committee a recommendation for such action as their findings warrant":

O. S. Fisher, Washington, D. C., *Chairman;* E. R. Jackson, Corvallis, Oregon; Earl Jones, Columbus, Ohio; J. C. Lowery, Auburn, Alabama; J. S. Owens, Storrs, Connecticut; and P. H. Stewart, Lincoln, Nebraska.

Early in October, Mr. Fisher requested the other members of the Committee to canvass their respective regions with respect to whether or not there should be a "separate extension program for extension workers" and the desirability of combining soils and crops topics into one program. Mr. Fisher was called away from Washington immediately before the annual meetings and requested me to review the questionnaires and present the results to the Society at the annual business meeting. Because the acting chairman had little opportunity to review the information collected or to discuss the problems with the chairman he called a meeting of the extension agronomists to discuss the relationship of the extension group to the Society. The following report is, therefore, based upon the opinion of this group as well as the comments which accompany the questionnaires.

The attendance of extension agronomists at the annual meeting of the Society has been small and an occasional worker considers the meetings of little interest. The Secretary reports that the membership of the extension workers has been spasmodic and lower in percentage than for the research and resident teaching groups. Participation has been irregular and attempts to organize discussions of extension methods have not been altogether satisfactory. An urgent need for closer association with the Society is evident in many of the written statements and was unmistakable in the discussion on November 18.

The extension specialist needs the close association with research which the annual meetings of this Society afford. Although some of the presentations may be highly technical there are enough which are of special interest to the extension agronomist to justify his attendance. Furthermore, the research worker can frequently be helped by interpretations of the extension man.

Although the questionnaire referred to showed a preference of 32 to 21 votes for separate meetings of extension at the annual meetings of the Society we do not wish to recommend this procedure at present. We think that more can be gained by infiltration with other programs. There are two types of presentations which we believe to have valuable possibilities. One, an interpretation of certain research presentations by extension men and, two, a description of certain field projects of agronomic interest and not extension methods as such. It should be possible to have these presentations as scholarly as research papers, and perhaps

of more interest than certain discussions in which there is little distinction between details and important principles.

Another recommendation is that a recognition be given to the interests of extension in the appointment of certain committees of the Society. Several of the problems with which these committees deal are even more closely associated with extension than research and we believe that we should ask for a fair representation.

The third proposal is that a permanent committee be named to give further consideration to the relation of the extension agronomist to the American Society of Agronomy. This committee might assist in developing programs and in advising the Executive Committee with respect to problems which have peculiar extension relationships. We recognize that there have been no policies of the Society which may have led to some of the situations which we believe to exist at present. The extension worker, through his own lethargy, perhaps is more responsible for this than any one else. We wish to urge that the extension workers see the long-time value of close association with other workers in these fields and of making their share of contributions in the agronomic field.

Respectfully submitted,
J. S. OWENS, *Acting Chairman.*

OFFICERS' REPORTS

REPORT OF THE EDITOR

Prof. J. D. Luckett, *Editor*, read a report which upon motion was adopted as follows:

During 1936 the JOURNAL has made further progress toward the solution of publication and financial problems that have beset it for the past few years, and it may be safely said now that we are definitely out of the woods.

The present editorial policies governing the JOURNAL are apparently working so well that we recommend their continuance for another year at least. So far as these policies affect you directly as contributors to the JOURNAL, they have to do chiefly with the practice of charging for extra pages beyond the limit of free publication—which stands now at 12 pages—and a $15.00 allowance for illustrations. Judging from past experience, these restrictions have not worked undue hardships on contributors and we have had much testimony to the effect that the more condensed articles appearing in the JOURNAL are a distinct gain.

The current volume will measure up to the average of the past few years in number of pages and general make-up. There will be 113 contributed papers, 13 notes, and 16 book reviews. Eleven papers have been returned to contributors as unsuitable for publication in the JOURNAL for one reason or another, while there are now 17 papers either awaiting publication or in the hands of reviewers.

It seems reasonable to assume that the JOURNAL will have adequate financial support during the coming year to make possible the publication of a volume of the same proportions as the current volume. In that event, the JOURNAL offers about as prompt publication as any similar medium with which we are familiar. Papers accepted by the JOURNAL today will appear in the February or March numbers, and equally prompt publication may be anticipated throughout the year.

Another consideration that might well enter into the selection of the JOURNAL as a medium of publication in 1937 is the marked increase in circulation that has been effected this past year. Beginning with an edition of 1,700 copies last Janu-

ary, it soon became necessary to step this up to 1,800 copies with a further increase to 2,000 copies early in the year. The circulation of the JOURNAL is now the largest in its history by more than 200 copies. While we do not wish to predict the 1937 circulation, we believe that in view of the nationwide stimulus that has been given to activities within the field of agronomy in all of its aspects, that it is reasonable to expect the JOURNAL to hold its own in the way of circulation and even to enjoy continued growth. This will mean, of course, that the JOURNAL will offer an increasingly important audience before which to present new developments in agronomy.

All present advertisers in the JOURNAL have either renewed their contracts for 1937 or have indicated that they intend to continue using the JOURNAL as an advertising medium. In addition we are assured of at least two new contracts and have reasonable expectation of still more. We cannot too strongly urge that you observe the admonition that appears at the bottom of our cover pages to "Please mention the JOURNAL to advertisers." It is a small thing in itself, but it means much to the advertiser to know that the money he is putting into the JOURNAL produces tangible results.

We are increasingly conscious of our deep indebtedness to those who serve so helpfully as reviewers and who aid us in arriving at what we hope are just and acceptable decisions regarding the papers submitted to the JOURNAL. Whatever you may *think* of our comments on your manuscripts, you have certainly been most charitable in your response and most gracious in your compliance. With each passing year, with its accumulation of new responsibilities and duties that come to all of us and with the growing complexity of this thing we call "agronomy," your Editor is increasingly aware of his limitations in dealing with many of the technical aspects of editing the JOURNAL and must rely to a greater extent than ever upon the assistance of those who are called upon to weigh the scientific value of the many contributions that come to us. A major share of the credit, then, for whatever success the JOURNAL may have attained this past year should go to this anonymous group of "associate editors".

No report of an officer of this society would be complete without acknowledgment of the splendid cooperation received at all times from the Secretary and Treasurer. It is to Dr. Brown's efficient handling of the membership and subscription lists that your JOURNAL arrives on time and follows you about as you move from place to place, as so many of you seem to do. Only those who are directly concerned with the business details of the Society can really appreciate what it means to have these details handled so expeditiously in the Secretary's office.

In conclusion I would like to say just a word to ally certain misgivings that some of you have expressed here this week as to how contemplated reorganization plans of the soils group might affect the JOURNAL. For the past several years the JOURNAL has not been in the least dependent upon the papers presented at the annual meeting for an adequate supply of manuscripts to maintain our publication schedule. The current volume, for example, will carry 12 or 14 papers presented at the annual meeting last year, about equally divided between crops and soils subjects. The other words, I would like to leave with you the thought that the JOURNAL is now essentially a record of current research in agronomy and that we have every reason to believe that this concept of the JOURNAL best meets the ideas and best serves the purposes of the members of the Society as a whole.

Respectfully submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE TREASURER

The report of the Treasurer was submitted as follows and referred to the auditing committee:

I beg to submit herewith the report of the Treasurer for the year November 25, 1935, to November 1, 1936.

Receipts

Advertising income	$ 545.48	
Reprints sold	1,752.26	
JOURNALS sold	305.06	
Subscriptions, 1936	1,738.05	
Subscriptions, 1935	24.45	
Subscriptions, 1936, new	706.40	
Subscriptions, 1937	51.45	
Dues, 1936	3,789.66	
Dues, 1935	365.00	
Dues, 1936, new	1,015.50	
Dues, 1937	40.00	
Total receipts	$10,333.31	
Balance in cash, Nov. 25, 1935	530.13	
Total income	$10,863.44	$10,863.44

Disbursements

Printing the JOURNAL, cuts, etc	$ 8,368.48	
Salary business manager and editor	679.30	
Postage (business manager and secretary)	214.05	
Printing, miscellaneous	292.94	
Express on JOURNALS	29.75	
Mailing clerk	80.27	
Refunds, checks returned, etc	44.65	
Miscellaneous, expenses annual meeting, etc	380.92	
Total disbursements	$10,090.36	$10,090.36
Balance on hand, Nov. 1, 1936		$ 773.08
Balance in trust certificate		296.99
Total balance in account		$ 1,070.07
Balance in cash in hand		$ 773.08

Respectfully submitted,
P. E. BROWN, *Treasurer.*

REPORT OF THE ASSISTANT TREASURER

Dr. A. G. McCall presented the report of the Assistant Treasurer, and it was referred to the auditing committee:

American Society of Agronomy in Account with Executive Committee of the First International Congress of Soil Science

November 23, 1935, to November 10, 1936

Receipts

Sale of Proceedings of First International Congress of Soil Science (1927)	$ 123.00
Interest on Savings Account of Prince Georges Bank and Trust Company, Hyattsville, Md	62.50
Membership dues from American members of the International Society of Soil Science	773.84

Credit by bank Aug. 28, 1936 for check of Marion Striker, on Bank of Nova Scotia, Puerto Rico (San Juan) deposited in lieu of one for same amount returned by bank Aug. 12, 1936		6.80	
Outstanding checks: No. 476 Nov. 9, 1936—$6.80 No. 477 Nov. 7, 1936— 6.32		13.12	
Balance on hand Prince Georges Bank and Trust Co., Nov. 23, 1935		$ 2,559.07	
			$ 3,538.33

Expenditures

Postage (stamps and envelopes for office correspondence in connection with membership records, proceedings orders, etc.)		$ 20.00	
The Rumford Press, Concord, N. Hampshire, for handling and shipping sets of Proceedings of First Internat'l Congress of Soil Science		45.42	
Deduction by bank, check of Marion Striker, Bank of Nova Scotia, San Juan, Puerto Rico; new check deposited in lieu of this one		6.80	
Bank charges on the above returned check		.25	
Premium on bond for Dr. A. G. McCall, Asst. Treas.		5.00	
Transmittal of dues collected from American members of the Society to Dr. D. J. Hissink, General Secretary		773.84	
Balance on hand Prince Georges Bank and Trust Co., Hyattsville, Md., as of November 10, 1936:			
Savings account (which includes $1,000 contribution to the endowment fund)	$2,565.20		
Checking account	121.82		
		$ 2,687.02	
			$ 3,538.33

Record of Distribution of Proceedings of First International Congress of Soil Science (1927), November 23, 1935, to November 10, 1936

On hand in storage with the Rumford Press, Concord, New Hampshire, as of Nov. 23, 1936		918 sets
Sold during the above period	14 sets	
Shipped to Dr. D. J. Hissink, 122 Verlengde Oosterweg, Groningen, Holland, for sale and distribution direct from his office	100 sets	
		114 sets
On hand in storage as of November 10, 1936		804 sets

Distribution as follows:

3 sets @ $11.50
5 sets @ 10.50
3 sets @ 6.50
2 sets @ 5.50
1 Vol. IV only @ $2.00 (counted as 1 set because it completed a broken set)

Collection as follows:

4 sets @ $11.50	$46.00	
5 sets @ 10.50	52.50	
1 set @ 6.50	6.50	
2 sets @ 5.50	11.00	
1 set @ 5.00	5.00	(old account ordered when price was $5.00)
1 Vo. IV only @	2.00	
	$123.00	

American Section, International Society of Soil Science, 1935–1936

Dues collected for 1935 (Number of members 65; some paid an advance for 2 years)	$34.50
Dues collected for 1936 (Number of members 113)	$56.50
Total on hand	$91.00

Submitted by

A. G. McCall,
Secretary-Treasurer, American Section and Assistant Treasurer, American Society of Agronomy

AUDITING COMMITTEE

Dr. C. J. Willard presented the report of the auditing committee as follows and upon motion it was adopted:

The books of the Treasurer and the report of the Assistant Treasurer of the American Society of Agronomy have been examined and have been found to be correct and in accord with bank statement.

Horace J. Harper
C. J. Willard, *Chairman*

REPORT OF THE SECRETARY

The report of the secretary was presented and accepted as follows:

I beg to submit herewith my report as Secretary for the year 1935 to 1936. The membership in the Society is the largest in the history of the organization. The figures by years are as follows:

Total Membership by Years

1908	121	1918	509	1928	823
1909	129	1919	473	1929	906
1910	176	1920	436	1930	943
1911	236	1921	592	1931	963
1912	295	1922	643	1932	949
1913	349	1923	561	1933	904
1914	397	1924	577	1934	868
1915	471	1925	646	1935	991
1916	586	1926	700	1936	1,166
1917	652	1927	767		

The changes in membership from last year are shown in the following figures:

Membership changes 1935–1936:

Membership, last report			991
New members, 1936		210	
Reinstated members		55	
Total increase		265	
Dropped for non-payment of dues	75		
Resigned	10		
Died	5		
Total decrease	90	90	
Net increase		175	175
Membership, November 1, 1936			1,166

The membership by years of election are given as follows:

Members by Years of Election

1908 Charter	25	1922	33
1908	7	1923	22
1909	2	1924	28
1910	12	1925	60
1911	21	1926	46
1912	11	1927	38
1913	13	1928	34
1914	10	1929	67
1915	17	1930	42
1916	22	1931	49
1917	10	1932	34
1918	10	1933	37
1919	8	1934	82
1920	22	1935	163
1921	31	1936	210
Total membership			1,166

The membership by states and countries is as follows:

Membership by States and Countries

Alabama	14	South Carolina	13
Arizona	11	South Dakota	10
Arkansas	7	Tennessee	9
California	44	Texas	45
Colorado	22	Utah	15
Connecticut	15	Vermont	3
Delaware	3	Virginia	24
District of Columbia	82	Washington	18
Florida	17	West Virginia	13
Georgia	17	Wisconsin	29
Idaho	8	Wyoming	4
Illinois	43		
Indiana	25	Canada	22
Iowa	57	Cuba	3
Kansas	55	Hawaii	11
Kentucky	11	Philippine Islands	2
Louisiana	17	Porto Rico	3
Maine	10	Africa	8
Maryland	18	Argentine	5
Massachusetts	12	Austria	1
Michigan	21	Brazil	2
Minnesota	31	British West Indies	1
Mississippi	11	China	24
Missouri	36	Denmark	2
Montana	9	Egypt	1
Nebraska	30	England	2
Nevada	2	Germany	4
New Hampshire	2	Greece	2
New Jersey	16	Honduras	2
New Mexico	9	Hungary	1
New York	43	India	9
North Carolina	21	Italy	1
North Dakota	13	Japan	8
Ohio	45	Jugoslavia	1
Oklahoma	19	Mesopotamia	1
Oregon	18	New Zealand	2
Pennsylvania	25	Palestine	1
Rhode Island	6	Panama	1

Poland	1	Sweden	1
Roumania	1	Switzerland	1
Scotland	1	Turkey	2
Siam	2	Uruguay	1
Spain	2	U. S. S. R	6
Total membership			1,166

The subscription list has been increased as the following figures will indicate:

Subscriptions last report		539
New subscriptions, 1936	154	
Subscriptions dropped	90	
Net increase	64	64
Subscriptions, November 1, 1936		603

The special representatives of the Society in the various states and bureaus of the U. S. Dept. of Agriculture have given us much aid in bringing in new members during the year. Special mention for the largest numbers of new members sent in should be made of Dr. R. V. Allison of the Soil Conservation Service, Prof. B. A. Madson of California, Dr. W. A. Albrecht of the University of Missouri, and Dr. H. K. Wilson of Minnesota.

The list of representatives is as follows:

Alabama, G. D. Scarseth
Arizona, Ian A. Briggs
Arkansas, R. P. Bartholomew
California, B. A. Madson
Colorado, W. H. Leonard
Connecticut, M. F. Morgan
Delaware, G. L. Schuster
District of Columbia, M. A. McCall, Bur. Plant Industry
P. L. Gile, Bur. Chem. & Soils
R. V. Allison, Soil Conservation Service
Florida, G. E. Ritchey
Georgia, J. R. Fain
Idaho, H. W. Hulbert
Illinois, J. J. Pieper
Iowa, J. B. Wentz
Indiana, S. D. Conner (deceased)
Kansas, H. E. Myers
Kentucky, P. E. Karraker
Louisiana, M. B. Sturgis
Maine, J. A. Chucka
Maryland, R. P. Thomas
Massachusetts, W. S. Eisenmenger
Michigan, C. E. Millar
Minnesota, H. K. Wilson
Mississippi, J. F. O'Kelly
Missouri, W. A. Albrecht
Montana, Clyde McKee
Nebraska, F. D. Keim
Nevada, V. E. Spencer
New Hampshire, O. R. Butler
New Jersey, H. B. Sprague
New Mexico, J. C. Overpeck
New York, R. G. Wiggans
North Carolina, L. G. Willis
North Dakota, T. E. Stoa
Ohio, Richard Bradfield
Oklahoma, H. J. Harper
Oregon, R. E. Stephenson
Pennsylvania, J. W. White
Rhode Island, T. E. Odland
South Carolina, H. P. Cooper
South Dakota, J. G. Hutton
Tennessee, O. W. Dynes
Texas, E. B. Reynolds
Utah, D. W. Pittman
Vermont, A. R. Midgley
Virginia, N. A. Pettinger (deceased)
Washington, E. G. Schafer
West Virginia, R. J. Garber
Wisconsin, L. F. Graber
Wyoming, T. J. Dunnewald

We owe all these men and many others who have given us help during the year, a very real debt of gratitude.

We also want to thank the officers of the Society and of the Sections and those members who have aided in getting up the programs for this meeting. The programs have become quite complicated affairs and it is a real problem to get them out promptly and in the best way. We appreciate all the help we have received and hope that there are not many errors.

We are all very proud of the JOURNAL and the Society is to be congratulated on its Editor. Professor Luckett carries the burden and it is due to him that the JOURNAL has achieved its high standing. We are certainly much indebted to him for all the work he does in keeping the JOURNAL up to its high standard.

We have paid the bills for all the issues of the JOURNAL for the year, 12 of them, from November 1935 to October 1936, inclusive, and we still have a balance in the treasury. All other bills have been paid, too, so the Society is solvent.

The meetings of the various sections of the Society have been reported in the JOURNAL and need only be referred to here. They have all been very successful. The Northeastern Section will meet at Atlantic City with the American Association for the Advancement of Science during the holidays, giving a joint program with Section O of the Association.

Respectfully submitted,

P. E. BROWN, *Secretary.*

FELLOWS

Past President M. A. McCall, acting for Vice-President F. D. Richey, announced the Fellows Elect and presented the diplomas. Those elected were Dr. W. L. Burlison, Dr. L. J. Stadler, and Dr. S. A. Waksman. (See pages 1025 to 1026 of this number of the JOURNAL.)

ANNUAL DINNER

The annual dinner of the Society was held on Thursday, November 19, at 6:30 p. m. at the Mayflower Hotel with 194 attending. The presidential address of Dr. R. N. Salter was given at the dinner.

REPORT OF THE NOMINATING COMMITTEE

Dr. G. D. Scarseth presented the report of the Nominating Committee nominating Prof. Emil Truog of the University of Wisconsin as Vice-President of the Society. Upon motion the report was adopted and the Secretary cast a unanimous ballot for Prof. Truog. Dr. F. D. Richey automatically succeeds to the Presidency and Dr. Richard Bradfield and Dr. O. S. Aamodt were announced as members of the Executive Committee representing the Soils and Crops Divisions, respectively. L. J. Stadler and G. W. Conrey were elected to represent the Society on the Council of the American Association for the Advancement of Science.

Meeting adjourned.

P. E. BROWN, *Secretary.*

OFFICERS OF THE SOCIETY FOR 1937

President, Frederick D. Richey, Bur. Plant Industry, U. S. Dept. Agr.

Vice-President, Emil Truog, Univ. of Wisconsin, Madison, Wis.

Chairman, Soils Section, Richard Bradfield, Ohio State University, Columbus, Ohio, and President of the Soil Science Society of America.

Chairman, Crops Section, O. A. Aamodt, Univ. of Wisconsin, Madison, Wis.

Editor, J. D. Luckett, New York Agr. Exp. Sta., Geneva, New York.
Secretary-Treasurer, P. E. Brown, Iowa State College, Ames, Iowa.

BUSINESS MEETING OF THE CROPS SECTION

THE meeting was called by Dr. H. B. Sprague of New Jersey, Chairman of the Section, for November 19, 1936. Dr. M. T. Jenkins, U. S. Bureau of Plant Industry, reported for the Sub-committee on Nomenclature of Corn Hybrids. A motion was made by Dr. M. A. McCall, U. S. Bureau of Plant Industry, that the committee on Nomenclature of Corn Hybrids be continued, pending the development of a Corn Conference, the committee to report next year. Motion carried.

Dr. Sprague reported for the Executive Committee on a canvass of the Crops Section regarding reorganization. He read the following report:

A PROPOSED PLAN FOR REORGANIZATION OF THE CROPS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

It is proposed that there be 3 subsections of the Crops Section: Subsection No. 1 shall embrace the fields of breeding, genetics and cytology; Subsection No. 2, the fields of physiology (including nutrition), morphology, and taxonomy; and Subsection No. 3, all other phases of crops not covered in the preceding subsections.

It is proposed that there be an executive committee consisting of 3 members elected annually, one of whom shall serve as chairman of the Crops Section, and shall be responsible for the activities of Subsection No. 3. The remaining 2 members of the executive committee shall act as secretaries of Subsections 1 and 2, respectively, and shall arrange suitable sectional programs for the annual meetings as desired by the membership of the Society. The chairman shall arrange for such programs or discussions on specific crops embracing various phases of plant sciences, on specific regional problems, on statistics and plot technique, on teaching and extension, as may be deemed desirable, and shall also provide for joint programs with soils groups when mutually desired.

It is also proposed that Crops Section programs at annual meetings shall not exceed 2½ days (plus ½ day for general meeting of the Society), with specialized programs occurring in the earlier periods of the meeting and the more general programs during the latter periods.

Dr. Sprague moved that the plan as outlined in the above proposal be accepted as a basis for a more specific plan to be prepared by the Executive Committee and presented at next year's meeting for action.

An amendment was offered by Dr. D. R. Dodd of Ohio that the report of the Executive Committee be accepted and referred to the future Executive Committee for reconsideration in providing a plan for reorganization at the meeting next year. The amendment was accepted by Dr. Sprague. Motion carried.

The Nominating Committee, composed of R. D. Lewis, *Chairman*,

M. T. Jenkins, and G. H. Cutler, presented the following nominations: O. S. Aamodt, Wisconsin, Chairman, and L. E. Kirk, Ottawa, and I. P. Trotter, Texas, members of the Executive Committee. The report was accepted by vote. Adjournment.—G. H. STRINGFIELD, *Temporary Secretary.*

MINUTES OF THE JOINT MEETING OF THE AMERICAN SOIL SURVEY ASSOCIATION AND THE SOILS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

THE meeting was called to order at 8:00 p.m., November 18, 1936, at the Mayflower Hotel, Washington, D. C., by M. F. Morgan, a member of the Committee on Constitution and By-laws, appointed at a joint session in Chicago (1935) of the members of the American Soil Survey Association and of the members of the Soils Section of the American Society of Agronomy, which was called for the purpose of considering the formation of a single soil science society.

Mr. Morgan called for the election of a temporary chairman. E. A. Norton was nominated by G. W. Conrey, after which a motion was made and passed that the nominations be closed and Mr. Norton be declared elected. Chairman Norton appointed Wm. A. Albrecht as secretary pro-tempore of the meeting.

Chairman Norton then called on Richard Bradfield to report for the Committee on Constitution and By-laws, who then began the presentation of the proposed constitution and by-laws for consideration and approval item by item as it had been printed in the program of the American Soil Survey Association and American Society of Agronomy.

E. A. Truog, as a member of the committee, was then called upon relative to the name of the organization and after pointing out the importance of the name in relation to library cataloging, made the motion that for Article I the name of the new soil science organization, "Soil Science Society of America" be adopted. This motion was duly seconded and passed.

(N.B. Each article and section of the proposed constitution and by-laws of the Soil Science Society of America were then considered separately and various amendments approved. The revised constitution and by-laws are presented below together with a statement concerning the newly formed Soil Science Society of America.)

After the recommendation of the committee for the adoption of the constitution and the by-laws for, and the amalgamation of the American Soil Survey Association and the Soils Section of the American Society of Agronomy into, the Soil Science Society of America had been adopted, the meeting was temporarily adjourned to reconvene as the first meeting of the Soil Science Society of America.

The chairman, E. A. Norton, called on T. M. Bushnell for the report of the Nominating Committee. This committee recommended the following officers: For President, Richard Bradfield; for Secretary, A. M. O'Neal. Motion was made and passed that the nominations be closed and that a unanimous ballot be cast for the above officers.

Chairman Norton then asked Dr. Bradfield to take the chair as president of the newly formed Soil Science Society of America, who responded with a few remarks after the applause expressing the approval of the preceding motion, and then asked the Secretary of the previous meeting to continue as secretary pro-tempore in the absence of A. M. O'Neal.

Richard Bradfield then made the report for the Editorial Committee appointed in 1935 with a supplemental report by Emil Truog. The former suggested publishing all papers in advance of the meeting with a call for manuscripts before August 15 and the production of the PROCEEDINGS by October 1, and a time limit on paper presentation of 10 minutes. The latter suggested publishing abstracts in advance of the meetings, the preparation for publication of the paper after its presentation, and the decision of the Editorial Committee on the publication of the paper. Both recommended the preparation of instructions on preparation of papers for publication. It was moved and passed that it was the sense of the assembly that for this year the latter suggestion seemed more feasible but that the plan adopted be left to the Executive Committee.

Mark Baldwin, of the Marbut Memorial Committee of the former American Soil Survey Association, suggested that this committee become one of the Soil Science Society of America. It was so moved and passed. The meeting was then adjourned.—WM. A. ALBRECHT, *Secretary Pro-tempore.*

THE SOIL SCIENCE SOCIETY OF AMERICA

THE American Soil Survey Association and the Soils Section of the American Society of Agronomy merged at their annual meeting held in Washington, D. C., November 17 to 20 to form the Soil Science Society of America.

The object of this new organization is to foster all branches of soil science. Sections have been organized in I, Soil Physics; II, Soil Chemistry; III, Soil Microbiology; IV, Soil Fertility; V, Soil Morphology, Classification, and Cartography; and VI, Soil Technology (including those aspects of soil reclamation and conservation not provided for in the other sections). The new organization will continue its close affiliation with the American Society of Agronomy, but its activities will not be limited to the usual agronomic applications of soil science. Anyone interested in any aspect of soil science will find a place in this new Society. Many plant physiologists, ecologists, geographers, horticulturists, foresters, highway, hydraulic, and agricultural engineers, and others will find papers of vital interest on its programs. The cooperation of all these specialists is needed to build a strong well-rounded Soil Science Society.

From 11 to 18 papers appeared on the programs of each of the Sections listed above at the recent Washington meeting. These papers (about 75 in all) will be published in Volume I of an annual series of PROCEEDINGS which will be ready for distribution early in 1937. This volume of PROCEEDINGS will supersede the ANNUAL BULLETIN of the American Soil Survey Association. Those interested in obtaining

a copy of the 1936 PROCEEDINGS are requested to send in their subscription at once as only a limited edition will be published. A list of options on both memberships and subscriptions with reduced club rates to subscribers to more than one publication is given below.

PLANS FOR 1937 MEETING

The next annual meeting of the Society will be held in Chicago, probably November 30 to December 3, 1937. Members wishing to present papers at this meeting are requested to communicate directly with the Chairman of the Section concerned. The names and addresses of the officers of the various Sections are listed below. Titles submitted must be accompanied by a 200 to 500 word abstract of the paper. It will probably be necessary to limit papers to 5,000 words. All papers appearing on the program are the property of the Society and may not be published elsewhere unless released by the Editorial Board. To ensure prompt publication of the PROCEEDINGS all manuscripts must be turned over to the Editorial Board of the Society in form ready for publication at the close of the meeting. To ensure careful consideration, titles and abstracts should be submitted as early in the summer as possible and in no case later than September 1.

OFFICERS FOR 1937

President, R. Bradfield, Dept. of Agronomy, Ohio State University, Columbus, Ohio. *Secretary*, O. M. O'Neal, Sugar Cane Soil Lab., Houma, La. *Treasurer*, P. E. Brown, Dept. of Soils, Iowa State College, Ames, Iowa.

I. Soil Physics: *Chairman*, H. E. Middleton, Div. of Research, Soil Conservation Service, Washington, D. C. *Secretary*, L. A. Richards, Dept. of Soils, Iowa State College, Ames, Iowa.

II. Soil Chemistry: *Chairman*, S. F. Thornton, Purdue Ag. Exp. Station, Lafayette, Ind. *Secretary*, E. E. DeTurk, Dept. of Agronomy, Univ. of Illinois, Urbana, Ill.

III. Soil Microbiology: *Chairman*, L. M. Turk, Dept. of Soils, Mich. State College, East Lansing, Mich. *Secretary*, N. R. Smith, Senior Bacteriologist, Bureau of Chemistry and Soils, U. S. D. A., Washington, D. C.

IV. Soil Fertility: *Chairman*, W. H. Pierre, Dept. of Agronomy, W. Va. Ag. Exp. Sta., Morgantown, W. Va. *Secretary*, H. J. Harper, Dept. of Agronomy, Oklahoma A. and M., Stillwater, Okla.

V. Soil Morphology: *Chairman*, L. C. Wheeting, Dept. of Agronomy, Washington State College, Pullman, Wash. *Secretary*, W. E. Hearn, Soil Survey Division, Bureau of Chemistry and Soils, U. S. D. A., Washington, D. C.

VI. Soil Technology: *Chairman*, L. R. Schoenmann, Dept. of Land Use, University of Michigan, Ann Arbor, Mich. *Secretary*, E. A. Norton, Soil Conservation Service, Des Moines, Iowa.

CONSTITUTION AND BY-LAWS OF THE SOIL SCIENCE SOCIETY OF AMERICA

NAME

ARTICLE I

The name of this organization shall be the Soil Science Society of America.

OBJECT

ARTICLE II

The object of this Society shall be to foster all phases of Soil Science.

MEMBERSHIP

ARTICLE III

Section 1. Any person or organization interested in the object of the Society shall be eligible for membership.

Section 2. Any member of the Soil Science Society of America is eligible to membership in any of the Sections of the Society.

SECTIONS

ARTICLE IV

Section 1. In order to provide opportunity for the consideration of specialized subjects in all branches of Soil Science, Sections shall be organized in each of the following fields: I. Soil Physics, II. Soil Chemistry, III. Soil Microbiology, IV. Soil Fertility, V. Soil Genesis, Morphology and Cartography, and VI. Soil Technology.

Section 2. The division of subject matter among the Sections shall be as follows:

a. Studies in which the soil is considered primarily as a physical system shall be presented before Section I—Soil Physics.

b. Studies in which the soil is considered primarily as a chemical system shall be presented before Section II—Soil Chemistry.

c. Studies in which the soil is considered primarily in relation to the growth of microorganisms shall be presented before Section III—Soil Microbiology.

d. Studies in which the soil is considered primarily in relation to plant growth shall be presented before Section IV—Soil Fertility.

e. Studies in which the soil is considered primarily as an individual entity, to be dissected and classified on the basis of its inherent characteristics shall be presented before Section V —Soil Genesis, Morphology and Cartography.

f. Studies in which the soil is considered primarily from the standpoint of tillage, drainage, irrigation, construction, or protection from erosion shall be presented before Section VI—Soil Technology.

JURISDICTION OF SECTIONS

ARTICLE V

Section 1. The various Sections shall have jurisdiction over all matters of interest to that section only.

Section 2. Matters which are of interest or concern to more than one section shall be referred to the Executive Committee for consideration.

Section 3. Each Section shall have the right to form such subsections as are necessary to promote the specialized interests of its members, subject to the approval of the Executive Committee of the Society.

OFFICERS OF THE SOCIETY

ARTICLE VI

Section 1. The officers of the Society shall be a President, Secretary, and an Executive Committee. The Executive Committee shall consist of the President, the Secretary, the most recent past President, the Chairmen of the several Sections, the Secretary-Treasurer of the American Society of Agronomy and the Editor of the Publications of the Society.

Section 2. The editor shall be selected by the Executive Committee.

ELECTION OF OFFICERS OF THE SOCIETY

ARTICLE VII

The President shall appoint a nominating committee of 3 members in advance of the annual meeting. This committee shall nominate a candidate for Secretary. Other nominations may be

made from the floor. The election of the Secretary shall be by ballot. The term of office shall be one year.

The Secretary shall automatically succeed to the Presidency.

DUTIES OF OFFICERS OF THE SOCIETY

ARTICLE VIII

Section 1. The President shall be the Executive officer of the Society. He shall preside over the meetings of the Society and its Executive Committee. He shall represent the Society on the Executive Committee of the American Society of Agronomy.

He shall organize a general soils program for the annual meeting when it seems desirable.

He shall with the help of the Executive Committee coordinate and arrange the programs of the Sections so that a conflict of interest will be avoided.

He shall continue to serve on the Executive Committee of the Society for one year following his retirement from the Presidency.

Section 2 The secretary shall keep the records of the Society.

He shall collect the manuscripts of papers on the General Program and transmit them to the Editor for publication.

Section 3. The Executive Committee shall formulate the policies of the Society as a whole, subject to the approval of the Society.

It shall coordinate the activities of the different Sections.

It shall have jurisdiction over all matters dealing exclusively with Soil Science but shall refer all matters of interest to both Soil and Crop scientists to the Executive Committee of the American Society of Agronomy.

It shall act upon all matters within the jurisdiction of the Society which arise between meetings of the Society.

It shall act as the Editorial Board of the Society.

OFFICERS OF THE SECTIONS AND THEIR DUTIES

ARTICLE IX

Section 1. The Chairman shall be the executive officer of the Section.

He shall preside at the meetings of the Section and of its Executive Committee.

He shall represent the Section on the Executive Committee of the Society.

He shall with the help of the Secretary organize the program of his Section and transmit it to the President for incorporation in the program of the Society.

He shall appoint a nominating committee of 3 members to select a candidate for Secretary.

He shall continue to serve on the Executive Committee of the Section for one year following his retirement from the Chairmanship.

Section 2. The Secretary shall be elected by ballot from the slate prepared by the nominating committee supplemented by any nominations from the floor.

He shall keep the records of the Section.

He shall collect the manuscripts of all papers on the Sectional Program and transmit them to the Editor for publication.

He shall assist the Chairman in organizing the program and at the expiration of his annual term he shall automatically succeed to the Chairmanship of the Section.

Section 3. The Executive Committee shall consist of the Chairman, the most recent past Chairman and the Secretary of the Section.

It shall outline the program of activities and shall formulate the policies of the Section, subject to the approval of the Section.

It shall act on all matters arising between the meetings of the Section.

TIME AND PLACE OF MEETING

ARTICLE X

Section 1. The Annual Meeting of the Society shall be held at a time and place determined by the Executive Committee of the Soil Science Society of America.

Section 2. Special meetings of either the Society as a whole or any Section thereof may be arranged by the Executive Committee concerned.

AMENDMENTS

ARTICLE XI

Amendments may be proposed (1) by the Executive Committee directly or (2) by petition of any 20 members of the Society. Notice of the proposed amendment shall be submitted to the members at least 30 days before the ballot is to be taken. The amendment may be adopted by a two-thirds vote of the members present at any annual meeting.

If in the opinion of the Executive Committee the proposed amendment should be acted upon before the next annual meeting it may be submitted to the members by mail. If it is approved by two-thirds of those returning their ballots within 30 days, it shall be adopted.

BY-LAWS

1. *Dues.* The annual dues for membership in the Society shall be $1.00. Members paying this fee shall be entitled to receive all the official communications of the Society and to participate in all its activities. They may present papers for publication in the official publications. They shall be entitled to subscribe for the publications at a reduced rate.

2. *Publications.* All papers listed in the Program of the annual meeting or suitable abstracts thereof, shall on the recommendation of the Editorial board be published in an Annual Volume of Proceedings.

3. *Collection of Dues and Subscriptions.* The Secretary-Treasurer of the American Society of Agronomy shall act as the Treasurer of the Soil Science Society of America but he shall keep the accounts of the Soil Science Society separate from those of the American Society of Agronomy.

He shall distribute each year about one month in advance of the annual meeting to each member of the Society (1) a program listing all papers to be presented at the annual meeting and (2) a card listing the various options regarding publications and membership with the request that the member check the Publications and Memberships desired and make payment for same to the Treasurer in advance of the annual meeting.

The membership and subscription options shall be as follows:

1.	Membership in the Soil Science Society of America (without publications)	$1.00
2.	Membership in the S. S. S. of America and Proceedings of the S. S. S. of America	4.50
3.	Membership in the S. S. S. of America and membership in the American Society of Agronomy and Journal of the A. S. A.	5.00
4.	Membership in the S. S. S. of America, Proceedings, membership in the A. S. A. and Journal of A. S. A.	9.00
5.	Membership in the S. S. S. of America and membership in the International Society of Soil Science	5.50
6.	Membership in the S S. S. ot America, Proceedings, and membership in the International Society of Soil Science	9.50
7.	Membership in the S. S. S. of America, Proceedings, membership in the A. S. A., Journal of the A. S. A., and membership in the International Society of Soil Science.	14.00

The above options may be changed when necessary by the Executive Committee. Each member shall indicate on the membership card the Section or Sections of the Soil Science Society of America in which he desires membership.

The membership lists of the Sections shall be made out from these cards.

4. *Expenditures.* Bills for any expenditures made by the officers of the Society in the transaction of official business shall after approval by the president of the Society be sumbitted to the Treasurer for payment.

The Executive Committee of the Soil Science Society of America and the American Society of Agronomy acting jointly shall determine the proportion of the income and operating expenses of the offices of the Editor and the Secretary-Treasurer which shall be paid either to or from the accounts of the Soil Science Society of America.

5. *Committees.* The Society and Sections shall appoint such standing and special committees as seems desirable for carrying on the work of the Society or Section.

6. *Quorum.* A quorum at the Annual Meeting of either the Society or Sections shall consist of at least 10 per cent of the members.

7. *Amendments.* These By-Laws may be amended at any annual meeting by a two-thirds vote of the members present.

STATISTICAL METHODS

WE are indebted to Dr. George W. Snedecor of Iowa State College for information regarding a meeting of a section of the American Statistical Association at the Stevens Hotel in Chicago on the afternoon of Wednesday, December 30, that will be of interest to many agronomists. The program follows:

STATISTICAL METHODS FOR EXPERIMENTAL DATA

Chairman: George W. Snedecor, Iowa State College.

An Experiment Planned with Confounding in Incomplete Blocks, W. J. Youden, Boyce Thompson Institute for Plant Research.

Correlation Between Mean and Standard Deviation in Field Experiments, F. R. Immer, University of Minnesota.

The Efficiency in Field Trials of Pseudo-Factorial and Incomplete Randomized Block Methods, C. H. Goulden, Dominion Rust Research Laboratory and Manitoba College of Agriculture.

The Analysis of Variance and Covariance in Non-orthogonal Data, S. S. Wilks, Princeton University.

MEETING OF NORTHEASTERN SECTION OF THE SOCIETY WITH SECTION O OF THE A. A. A. S.

A SYMPOSIUM on pasture and forage crops in the northeastern states will feature the joint program of the Northeastern Section of the Society and Section O of the American Association for the Ad-

vancement of Science at the Ritz Carlton Hotel at Atlantic City on December 29. An outline of the symposium follows:

MORNING SESSION

An Inventory of Crops and Their Improvement for Pasture in the Northeastern States....Dr. H. B. Sprague, New Jersey Agricultural Experiment Station

The Chemical Composition of Leguminous Forage Crops as Affected by Stage of Growth..Dr. A. J. Pieters, Bureau Plant Industry, U. S. Dept. of Agriculture

The Influence of Grazing, Management, and Plant Associations on the Chemical Composition of Pasture Plants (illustrated).
Prof. D. B. Johnstone-Wallace, Cornell University

The Influence of Stage of Growth on the Composition of Silage.
Dr. R. G. Wiggans, Cornell University

AFTERNOON SESSION

Technic in Determining the Values of Pastures..B. A. Brown, Connecticut (Storrs) Agricultural Experiment Station

Modification of the Plant Composition of Pastures by Fertilizer Treatments
Dr. W. H. Pierre, University of West Virginia

Modification of the Plant Composition of Pastures by Soils.
Dr. A. R. Midgley, University of Vermont

Interpretation of Variations in Plant Composition in Relation to Feeding Value.
Dr. L. A. Maynard, Cornell University

In the absence of Dr. H. K. Hayes, retiring vice-president of Section O, Dr. H. K. Wilson of the University of Minnesota will present Dr. Hayes' presidential address on "Agricultural Research in China."

"PERENNIAL" WHEAT IN THE U. S. S. R.

FROM the laboratory of Doctor N. V. Tzitzin located at the Omsk Institute at Omsk, Siberia, come reports of progress in his work on perennial wheats—crosses of wheat with Agropyrum. This year for the first time the hybrids were sown by grain drills. Among the various new forms were found strains that mature 5 to 8 days earlier than the "Lutescens—062," which is considered the earliest producing wheat in northern Russia. Some of the forms gave yields of grain 50% greater than wheat, and the grain is described as being of excellent milling quality.

The two perennial wheats Nos. 34085 and 23086 are being rapidly multiplied, and not withstanding summer drought there will be over an acre planted next spring.

At the All Union Agricultural Fair which opens July 6, 1937, there will be a special series of plats devoted to Dr. Tzitzin's hybrids. Twenty-five wheat-agropyrum hybrids will be planted, and over 80 square meters of land will be devoted to these hybrids. The winter hybrids have already been planted.

There will also be special plats of hybrids and new varieties of wheats and other crops produced by Dr. G. K. Meister of the Saratov Station, and by Dr. T. D. Lysenko of the Odessa Plant Breeding Station.

NEWS ITEMS

The *New York Times* of December 14 reports unofficially that the Soviet government has cancelled the Seventh International Congress on Genetics which was to have been held in Moscow in August 1937. The same dispatch also reports the arrest of Prof. N. I. Vaviloff, head of the All-Union Institute of Plant Industry at Leningrad, and well known to agronomists in America where he has traveled extensively.

G. L. SCHUSTER, Professor of Agronomy at the University of Delaware, has been named Assistant Dean of Agriculture at the University, effective January 1.

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